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THE UNIVERSITY OF ALBERTA

PREDICTION OF FROST HEAVE USING THE SEGREGATION POTENTIAL THEORY

by

WILLIAM THOMAS HORNE

©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

FALL 1987

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled *Prediction of Frost Heave Using the Segrgation Potential Theory* submitted by William Thomas Horne in partial fulfilment of the requirements for the degree of Master of Science.

D.C. Sego

Supervisor

K.C. Cheng

Date....October 5, 1987

To

Mom and Dad

ABSTRACT

A numerical model was used to predict the magnitude of frost heave for various climatic conditions, soil types and water table depths. The heave is predicted using a model developed by Konrad (1980). The results are presented in a manner to that enables an upperbound estimate of the frost heave magnitude to be predicted for particular environmental conditions. The magnitude of predicted heave is dependent on the segregation potential of the soil, the depth to the water table and the ground freezing index.

The use of insulating layers to reduce frost heave under unheated buildings was studied using a two dimensional model for the heat flow, coupled with a simplified method of frost heave prediction. Insulating layers were found to reduce the magnitude of frost heave substantially. The effectiveness of different insulation configurations around footings of unheated buildings were examined for various ground freezing indices, segregation potentials and footing depths.

The segregation potential of a soil is influenced by the type and amount of clay contained in a soil. Only 1 to 2% clay content is sufficient to produce potentially damaging segregation potentials. A correlation between segregation potential and soil properties is examined, however no definite conclusions are possible without extensive testing of soils.

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Sincere thanks go to Dr. D.C.C. Sego for suggesting this interesting topic. His encouragement and genuine concern enabled the completion of this work.

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1.0 INTRODUCTION

In Canada, extensive damage is caused to roads, airfields, pipelines and unheated structures by frost heave. Damage results from the deformations caused by the build up of ice lenses in the soil and/or the thaw weakening that occurs as the ice melts. The heave results in servicibility problems or structural damage to the structures.

Frost heave has been a topic of considerable research in the past. It has been concluded that frost heave is caused by temperature induced suction gradients in the frozen zone (Mageau, 1978 and Konrad, 1980). Konrad (1980) examined the factors which influence the amount of water that flows to the ice lens for given temperature conditions. With an understanding of the frost heave mechanism, Konrad was able to develop a model which predicts the magnitude of frost heave within a soil for a given thermal situation. Nixon (1982) used this frost heave model to analyze a field freezing test and found good agreement between predicted and measured results.

Knowledge of the frost heaving process and the ability to predict frost heave can lead to two important developments. The first is the formulation of more useful and rational frost susceptibility classifications for soils. The frost susceptibility classifications presently in use give no quantitative estimates of the amount of frost heave that will occur. They also make no mention of the climatic conditions at the site. Under some climatic conditions, a soil may cause potentially dangerous heave, whereas it would cause very little damage under different climatic conditions. The second development is that knowledge of the frost heaving process enables quantitative predictions to be made regarding the effectiveness of measures undertaken to reduce the damage caused by frost heave.

1.1 Scope of the Thesis

The aim of this thesis is to provide a basis for a design manual on the control of frost heave under unheated buildings. The thesis explores a number of topics to satisfy this aim.

Frost susceptibility of soils is examined by analyzing soil properties which cause a soil to be frost susceptible. This is quantified using the segregration potential of the soil (Konrad, 1980; and Konrad and Morgenstern, 1981).

The magnitude of frost heave is predicted by a numerical model for various climatic and soil conditions. Frost heave design charts are derived so that an estimate of the magnitude of frost heave can be made for a particular site. The influence of insulating layers in reducing the magnitude of frost heave is evaluated for various insulation configurations, footing depths and climatic conditions.

The results presented in the thesis can be used to decide whether frost heave is hazardous for a particular site. If frost heave is potentially dangerous, solutions are presented to reduce the magnitude of heave.

In Chapter 2 the model used in the study is presented. The factors that influence the magnitude of frost heave are discussed.

In Chapter 3 the frost susceptibility of soils in terms of the segregation potential model is evaluated. An attempt is made to correlate soil index properties to segregation potential. The frost susceptiblity classifications presently in use are examined to evaluate how applicable they are in light of the segregation potential model.

In Chapter 4 the magnitude of frost heave is predicted for various soil types, segregation potentials, climatic conditions and water conditions.

In Chapter 5 the control of frost heave under unheated buildings is examined. A two dimensional heat flow model along with the segregation potential model is used to evaluate the effectiveness of insulating layers to reduce the magnitude of frost heave beneath footings.

The final chapter outlines the conclusions and recommendations of this study.

2.0 FROST HEAVE MODEL

2.1 Introduction

In the past there has been a considerable amount of research on frost heave models and methods of estimating the amount of heave that occurs as a soil freezes. The phenomenon of frost heave results from an interaction of heat and mass transfer. This interaction has been modelled by such authors as Harlan (1973), Kay et al. (1977), Aguirre-Pente et al. (1977), Taylor and Luthin (1978), Guymon et al. (1980), and Hopke (1980). Konrad (1980), Loch (1981), O'Neill (1983) and Anderson (1984) present summaries of the current knowledge of ice segregation and mathematical models used to predict frost heave.

Recently some attempts have been made to estimate the magnitude of frost heave. Shixiong and Qiong (1983) have developed analytical formulas to estimate the amount of frost heave. They describe the moisture migration process by the theory of unsaturated soil water movement. No laboratory results are presented to support their analytical models.

Guymon et al. (1983) applies the frost heave model described by Guymon et al. (1980) to four field cases of frost heaving soils. Johnson et al. (1986) uses a similar model for the prediction of frost heave for roads and airfields. In both cases the prediction of frost heave from the mathematical models is good. However, to achieve these predictions the models have to be calibrated to the field results using a soil hydraulic conductivity correction factor. This parameter accounts for the decreased hydraulic conductivity in the freezing or thawing zones. This factor is found to vary significantly for different soil types. The authors do not indicate how this correction factor can be estimated for different soils. Horiguchi and Miller (1983) state that difficulties still remain in the determination of frozen conductivity in frozen materials. Without knowledge of this correction factor for a particular soil, the model is deficient as an engineering model for the prediction of frost heave.

Goto and Takahashi (1982) propose an empirical formula for estimating the frost heave magnitude in laboratory studies. The formula includes the effect of overburden pressure and cold side temperature. Calculation of the heave requires knowledge of α and β which are generic constants of the soil. The empirical formula estimates the magnitude of heave for laboratory freezing tests with good accuracy. This empirical formula has no theoretical basis and has not been applied to a field case. It is also noted that the data for α and β for a particular soil has considerable scatter.

Many other researchers have attempted to relate the magnitude of frost heave to properties of the freezing soil system through the use of laboratory tests. Loch (1979) related the water intake flux to the unfrozen soil length. Penner and Ueda (1977 and 1978) related water intake flux to applied pressure and cold side step temperature during laboratory experiments. Kaplar (1968 and 1970) and Penner (1972) related the ice segregation of soils to the heat extraction rate. Hwang (1977) analyzed freezing tests using an "Ice Segregation Ratio". This is the ratio of heave to the thickness of frozen soil. The extensive testing program of Konrad (1980) showed that these relations by themselves were inadequate to model frost heave in a freezing soil, since not all the parameters that influence the frost heave and frost heave rate within a freezing soil were included in each model.

Konrad (op cit.) presented a model of frost heave that includes the effects of the permeability of the frozen soil, the segregational freezing temperature, the temperature gradient through the frozen fringe, the suction at the frost front, the rate of cooling, and the applied pressure. The model has been used to successfully analyze both laboratory and field freezing experiments by Konrad (1980) and Nixon (1982). The Konrad model uses parameters to predict heave that can easily be determined in the laboratory. The Konrad model is used for this study because it takes into account the main factors which control the amount of frost heave and it is a practical engineering solution for the prediction of frost heave.

Nixon (1987) discusses methods of predicting the magnitude of frost heave. He shows how Konrad's Segregation Potential model can be used estimate the magnitude of heave.

2.2 The Segregation Potential Model of Frost Heave

Since the Segregation Potential Model is used, it is appropriate to present the theoretical background and the formulation of the model in detail.

A freezing soil consists of frozen soil, an ice lens, a frozen fringe, and unfrozen soil. These components are illustrated in Figure 2.1. The unfrozen soil is located below the 0°C isotherm, which is termed the frost front. Between the frost front and the final ice lens is the frozen fringe. The soil in this zone is only partially frozen. Some unfrozen water remains as adsorbed films on the surfaces of the fine grained particles. The frozen fringe was also noted by Miller (1972) and Mageau (1978).

From thermodynamics principles the Clausius Claperyon equation is developed. It states that a suction is developed due to the unfrozen water in the frozen soil being supercooled. Collins (1987) presents a derivation of the thermodynamic equations involved in a freezing soil. Water from the unfrozen soil can migrate through the unfrozen films under the action of this temperature induced suction gradient. As the temperature in the frozen fringe decreases the thickness of the adsorbed water films around the soil particles decreases. This results in a lower permeability within the frozen fringe, and water transfer is inhibited. At this point the water collects to form an ice lens within the frozen soil. The temperature at the base of this ice lens is defined as the segregational freezing temperature (T_s).

Ultimately, the amount of heave a soil experiences can be shown to be a function of the average permeability of the frozen fringe (K_{ff}), the segregational freezing temperature (T_s) and the thickness of the frozen fringe (d). The thickness of the frozen fringe depends on the temperature gradient within it. The permeability of the frozen fringe and the segregational freezing temperature are unique soil properties, and are difficult to measure from a normal freezing test (Konrad and Morgenstern, 1981). Konrad (1980) showed that at the onset of the formation of the final ice lens the amount of heave can be related to properties of the freezing system which are easily obtained from laboratory experiments. These properties are the temperature gradient in the frozen fringe (grad T_{ff}), and the segregation potential (SP_0) of the soil. The segregation potential incorporates the permeability of the frozen fringe and the segregational freezing temperature, which control the frost heave in a soil.

2.2.1 Derivation of Segregation Potential (After Konrad, 1980)

The suction at the top of the ice lens can be shown to be related linearly to the segregational freezing temperature using the Clausius Claperyon equation. This can be derived by assuming the ice lens is under zero external pressure. By virtue of the Clausius Claperyon equation the water pressure at the base of the ice lens is:

$$Pw = L(T_s{*}-T_o{*})/(V_w \cdot T_o{*}) = M \cdot T_s \qquad 2.1$$

where

$T_s{*}$ = temperature at the base of the ice lens (°K)

M = a constant equal to $L/V_w \cdot T_o{*}$

$T_o{*}$ = the freezing point of water (°K)

L = the latent heat of phase change

T_s = temperature at the base of the ice lens (°C) (Assuming the freezing point of water = 273.15°K = 0°C)

V_w = the specific volume of water.

In terms of total head:

$$Hw = (Pw/\gamma_w) + Z \qquad 2.2$$

where

γ_w = the unit weight of water

Z = the elevation head

In most laboratory situations the elevation head can be neglected, therefore:

$$Hw = Pw/\gamma_w = M \cdot T_s/\gamma_w = M' \cdot T_s \qquad 2.3$$

where

$M' = M/\gamma_w$

Velocity of water through the frozen fringe can be approximated by Darcy's law using:

$$V = K_{ff}\frac{\Delta H}{d} \qquad 2.4$$

where

V = Velocity of water through the frozen fringe

d = frozen fringe thickness

K_{ff} = the average permeability of the frozen

ΔH = head difference between the base of the ice lens and the frost front

The head difference between the base of the ice lens and the frost front is:

$$\Delta H = Hw - hu \tag{2.5}$$

where

hu = the suction at the frost front.

The suction at frost front can be determined by Darcy's equation applied through the unfrozen soil assuming that steady state flow exists through the unfrozen soil.

The thickness of the frozen fringe (d) can be determined from the temperature gradient in the frozen fringe and the segregational freezing temperature, assuming that the temperature profile through the frozen fringe is linear.

$$d = \frac{T_s}{\text{grad } T_{ff}} \tag{2.6}$$

where

grad T_{ff} = the temperature gradient through the the frozen fringe.

Combining equations 2.4, 2.5 and 2.6 gives the following expression:

$$V = K_{ff}\left[\frac{Hw - hu}{T_s}\right]\text{grad } T_{ff} \tag{2.7}$$

or

$$V = SP_0 \cdot \text{grad } T_{ff} \tag{2.8}$$

where

$$SP_o = K_{ff}\left[\frac{Hw - hu}{T_s}\right] \qquad 2.9$$

Hence the water intake velocity equals the product of the temperature gradient across the frozen fringe and the segregation potential(SP_o) of the soil. The segregation potential of the soil is a function of the intrinsic parameters T_s and K_{ff}. It is therefore a unique soil parameter. The experimental determination of SP_o from laboratory freezing tests is relatively straightforward. It can be calculated from two measureable quantities; the intake velocity, and the temperature gradient in the frozen fringe.

Konrad (op cit.) carried out laboratory tests using Devon Silt, a frost susceptible silty clay. His results verified the preceeding theoretical development.

2.2.2 The Effects of Suction at the Frost Front

The magnitude of suction at the frost front depends on the permeability of the unfrozen soil, the distance to the water source and the inflow velocity to the base of the ice lens.

Experiments have demonstrated that the segregation potential of a soil decreases with an increase in suction at the frost front, as equation 2.9 predicts. As the suction at the frost front increases, the potential difference between the base of the ice lens and the frost front decreases. This causes a decrease in the hydraulic gradient across the frozen fringe, which results in a decrease in the segregation potential. This is illustrated in Figure 2.1. Therefore the suction at the frost front must be known in order to predict the magnitude of frost heave. The suction at the frost front can be determined by applying Darcy's law to the unfrozen soil.

2.2.3 The Effect of Cooling Rate

The degree of thermal imbalance of the system also affects the amount of frost heave (Jones, 1981 and Loch, 1979). Konrad (1980) and Konrad and Morgenstern (1982a) developed a model to simulate heave during unsteady state heat flow. The degree of thermal imbalance was characterized by the rate of cooling which was taken as the change in average temperature within the frozen fringe per unit time.

From experimental results the variation of SP with the rate of cooling and the suction at the frost front was determined. This variation of SP can be expressed in a three dimensional surface with axis for the segregation potential (SP), rate of cooling (RC) and suction at the frost front (Pu). This surface will be referred to as the SP-RC-Pu surface. The surface for Devon Silt is illustrated in Figure 2.2.

2.2.4 The Effects of Overburden Pressure

It has been known for some time that pressure reduces the heave rate (Beskow (1935), Penner and Ueda (1977), Aitken (1974)). This phenomenon can be explained using

Konrad's frost heave model (Konrad, 1980, and Konrad and Morgenstern, 1982b).

The suction at the base of the ice lens is a function of both the temperature and the pressure applied to the ice. Increasing the overburden pressure decreases the suction potential at the base of the ice lens.

The surcharge pressure also causes an increase in unfrozen water and therefore an increase in the thickness of the water film on the soil particles. This leads to a colder segregation freezing temperature which means a thicker frozen fringe. All of these factors contribute to the result that an increase in overburden pressure causes a decrease in the segregation potential (Konrad, 1980). It has been found that for various soils the effect of applied loads on the segregation potential can be accounted for by:

$$SP_o = a \cdot \exp(-b \cdot P_e) \qquad 2.10$$

where

P_e = the overburden pressure

a and b are soil constants determined from frost heave tests.

2.2.5 Summary

For an accurate determination of frost heave using the Konrad model several parameters are required. The first is the segregation potential of the soil and how the segregation potential varies with suction at the frost front, rate of cooling, and overburden pressure. The second parameter is the temperature gradient in the frozen fringe. This can be determined by solution of the heat flow equations. The application of this model to field situations will be outlined in detail in Chapter 4.

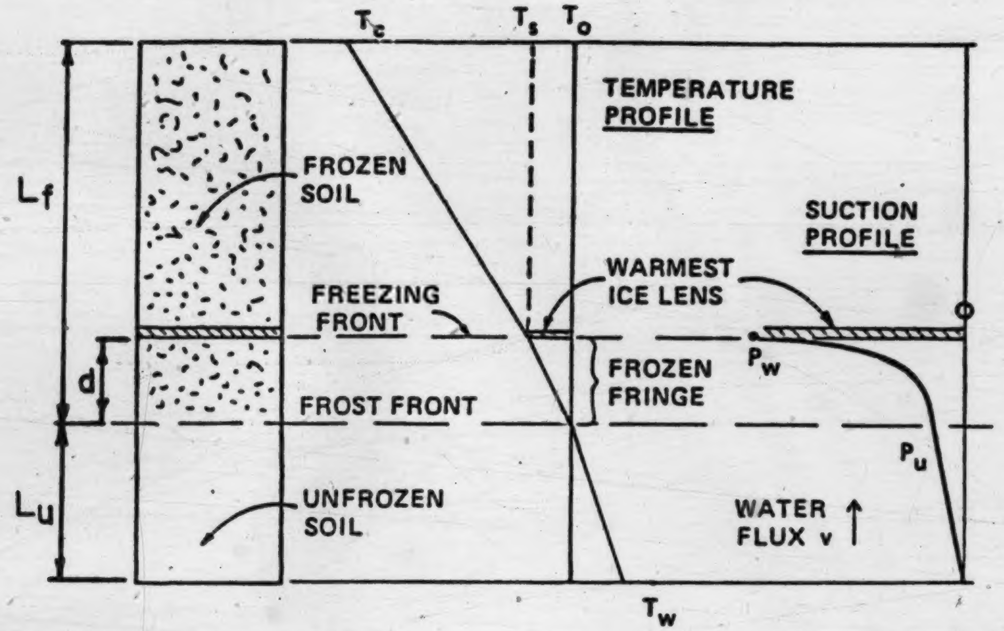

T_c
T_s
T_o
TEMPERATURE PROFILE
L_f
FROZEN SOIL
SUCTION PROFILE
WARMEST ICE LENS
FREEZING FRONT
O
P_w
d
FROZEN FRINGE
FROST FRONT
P_u
L_u
UNFROZEN SOIL
WATER FLUX v
T_w

Figure 2.1 Components of a Freezing Soil (Modified from Konrad and Morgenstern, 1984.)

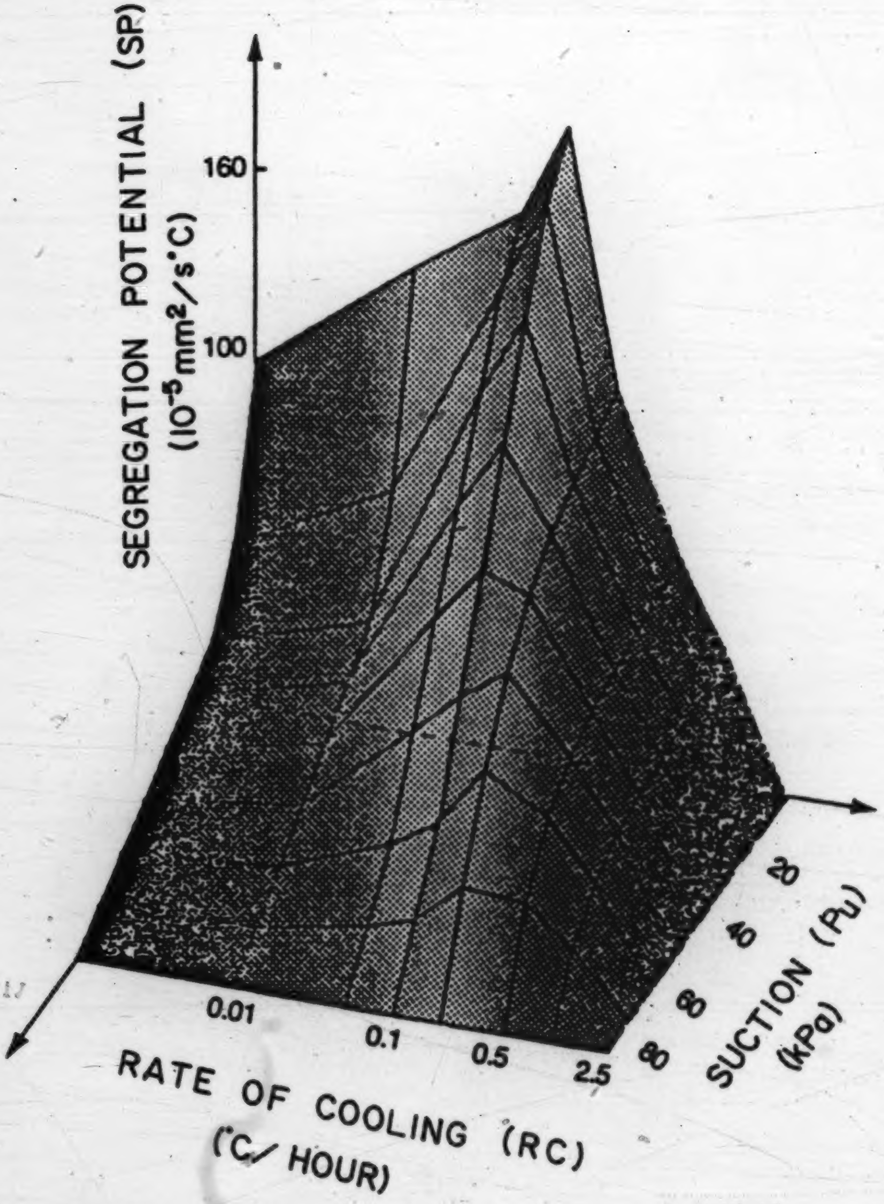


Figure 2.2 Characteristic frost heave surface for Devon Silt (Modified from Konrad and Morgenstern, 1984.)

3.0 FROST SUSCEPTIBILITY OF SOILS

3.1 Introduction

The frost susceptibility of a soil is defined by the magnitude of damage that the soil causes as it freezes and thaws. This amount of damage depends on the soil properties, the availability of water at the freezing front, the climatic conditions and the tolerable deformations of the structure. In the past the frost susceptibility of soils has usually been related to soil properties with no mention of the climatic conditions, availability of water to the freezing front or deformations caused by frost heave. Thus the frost susceptibility classifications are only applicable for the region and conditions for which they were developed.

If the Konrad model is used for the prediction of the magnitude of frost heave, the frost susceptibility of a soil is defined by the segregation potential of the soil. The value of segregation potential depends on the suction at the frost front which is a function of the permeability of the unfrozen soil and the depth of the water source. A prediction of the amount of damage can be made by estimating the magnitude of frost heave at a particular climatic and water table condition. Chapters 4 and 5 are devoted to estimating the magnitude of frost heave for particular conditions. The amount of heave caused in each situation depends on the segregation potential of the soil.

Ideally the segregation potential of a soil is determined from laboratory freezing tests, however it is not always possible to conduct freezing experiments. It is therefore desirable to relate the segregation potential of soil to readily obtainable soil characteristics.

This chapter examines the properties of soil which influence the segregation potential. Soils for which segregation potential information is available will be examined and an attempt will be made to relate soil properties to segregation potential. These results will be compared to the other frost susceptibility classifications presently in use.

3.2 Soil Properties That Influence Segregation Potential

As discussed in chapter 2, the segregation potential of a soil is dependent on boundary conditions such as the suction at the frost front, the rate of cooling and overburden pressure at the ice lens. It also varies according to the soil characteristics which affect the average permeability of the frozen fringe and the segregational freezing temperature. The segregational freezing temperature occurs where no water flow takes place due to the very low permeability of the freezing soil. Therefore, the segregation freezing temperature depends on soil properties that influence the permeability of the frozen fringe and the relationship between unfrozen soil water and temperature.

The permeability of the frozen fringe is a result of the adsorbed water films on the surface of the soil particles. The unfrozen water around the particles results from surface forces, which consist of capillary and adsorption forces. The surface forces decrease as the distance from the particles increase. The freezing point depression of the fluid will vary with the intensity of these surface forces. Johnston (1981) describes the main factors influencing the properties of the adsorbed water films in saturated frozen soils. The factors are temperature, specific surface area of the solid phases, pressure, chemical and mineralogical composition of the soil and other physico-chemical characteristics such as the nature of exchangeable cations and solute content and composition. Anderson and Morgenstern (1973) and Mageau (1978) present a summary of the research carried out on unfrozen water in soils. Mageau (1978) summarizes that the unfrozen water is a somewhat structured film with properties different from those of free water. The structure and thus viscosity becomes more pronounced as the distance to the particle surface decreases. Therefore, it is not only the amount of unfrozen water that affects the permeability of the frozen fringe, but also the thickness of the adsorbed water film.

The mineralogical composition of the fine grained soil particles influences the unfrozen soil water in the frozen fringe. This affects both the frozen fringe permeability and the segregation freezing temperature. Rieke et al. (1983) and Lambe et al. (1969) examined the influence of mineralogical composition on the frost susceptibility of soils.

Lambe et al. (1969) conducted freezing tests using a constant rate of frost penetration. This resulted in varying rates of heat extraction during the test. It has been shown by Jones (1981) that the rate of heave versus the rate of heat extraction differs for various soils which influence Lambe's results. Lambe found that different types of minerals in the soil mixture can enhance or inhibit frost heave. The heave inhibiting effects result from plastic clay minerals. This could be due to the clay mineral causing a lower unfrozen permeability which causes a higher suction at the frost front. He also found clay minerals to be more potent than non clay minerals in both their heave producing and heave inhibiting effects. The minerals with relatively high frost heave producing ability are, in increasing order: muscovite, calcite, magnesite, iron montmorillonite, illite, kaolinite, nontronite and attapulgite. If montmorillonite is the soil fine, the rate of heave can vary over a considerable range depending on the exchangeable ion. For clay contents between 3 to 6% by weight the increasing order of heave by exchangeable ion was: sodium, magnesium, lead, potassium, calcium and iron.

Rieke et al. (1983) also found the mineralogy of sand-silt-clay mixtures to affect the segregation potential.

His findings confirmed the observations of Lambe et al. (1969) that kaolinite mixtures have a higher frost susceptibility than montmorillonite. Anderson and Morgenstern (1973) noted that although montmorillonite has a higher unfrozen water content than kaolinite, the thickness of the unfrozen water zone is greater in kaolinite than montmorillonite. This fact leads to the hypothesis that the thickness of the unfrozen zone is more important to the segregation potential than the unfrozen water content. This hypothesis is evaluated further in the next section. The data of Rieke et al. (1983) also shows that segregation potential increases rapidly with the addition of small amounts of clay mineral to the soil.

The orientation of the particles will also influence the permeability of the soil in the frozen fringe. This was indirectly proven by Reed et al. (1979). They reported the effects of fabric on the frost heave rates obtained from rapid freeze tests of three soils with varying amounts of silt and kaolinite having been compacted to various degrees. The degree of compaction was found to influence the heave rate significantly. In general it was found that samples compacted on the dry side of optimum moisture content heaved more than samples compacted at the optimum moisture content or on the wet side side of optimum. Increasing the compactive effort decreased the heave for soils on the dry side, but did not decrease the heave of the soils at optimum or on the wet side. This decrease in heave is most likely caused by a decrease in the soils' permeability. However, it is uncertain whether this decreased permeability is apparent in the frozen fringe or only the unfrozen soil, since both will cause a decrease in the amount of frost heave. A decrease in unfrozen soil permeability results in higher suction at the frost front which reduces the amount of frost heave.

In summary, the soil properties with the greatest influence on the segregation potential of a soil are the soil structure, and the mineralogy of the clay and the amount of clay. These factors contribute to the unfrozen water content and the thickness of the unfrozen soil water film.

3.3 Correlating Segregation Potential to Soil Properties

It is desirable to relate segregation potential to common soil properties. If a correlation is achieved a soil's segregation potential can be estimated without conducting freezing tests unless an accurate value of the segregation potential is required.

The amount of fine grained material and the soil mineralogy is reflected by Atterberg limits and grain size information. Soil structure is more difficult to determine but is reflected by the void ratio and the soil density. Soil structure may also be indicated by a pore size distribution. Frost susceptibility has been shown to be related to pore size distribution by Taber (1930), Csathy and Townsend (1962), Reed et al. (1979) and Lovell (1983).

In the past, extensive research has been carried out on freezing soils. Some of the data in the literature can be interpreted in terms of segregation potential. Table 3.1 lists soils for which the segregation potential has been experimentally determined, back calculated from laboratory investigations, or back calculated from field investigations.

These soils, together with soils which Rieke et al. (1983) tested, will be used to explore the relationships between segregation potential and basic soil properties. The relationship between soil structure and segregation potential can be not investigated, due to the lack of available information in the literature. A brief description of the soils and the testing procedures used to obtain their soil freezing characteristics follows.

Aitken (1974) conducted field tests evaluating the influence of overburden pressure on the heave rate. Five 7.6 m x 7.6 m boxes were loaded to 0, 14, 28, 41 and 55 kPa and left to heave naturally for five consecutive years. The soil at the site was Fairbanks silt, a low plastic silt. The properties of the soil varied over the site. This introduces some uncertainties when correlating segregation potential to soil properties. Konrad (1980) determined the value of segregation potential by simulating the frost penetration and heave. He used a simplified method of frost heave prediction, where the temperature gradient in the frozen fringe equals the cold side temperature divided by the frost penetration depth. While this relation does not take into account all of the processes involved, its degree of accuracy is considered adequate for this study, given all of the unknowns in interpretating the field test in terms of segregation potential.

Loch and Kay (1978) conducted freezing tests on New Hampshire silt. The tests were carried out using constant warm side and cold side temperatures. The temperature gradients and overburden pressures were varied for six tests. The warm side temperature was approximately 3°C causing a large unfrozen length which results in reduced segregation potential. An estimate of the segregation potential was made from the water intake and the measured temperature gradient. The segregation potential at no overburden pressure can be estimated by assuming the relation between segregation potential and applied overburden pressure is logarithmic.

The soil properties for New Hampshire silt were reported by McGaw (1977). The Atterberg limits and some grain size information were listed, however the percent clay was not reported. An estimate of the percent clay can be made by considering the clay mineralogy and the activity of the soil.

Devon silt is the soil Konrad (1980) used during the development of the segregation potential model. There has been an extensive amount of laboratory testing done on this soil and the soil properties are described in detail in his thesis. The segregation potential of Devon silt has been determined for varying rates of cooling, suction at the frost front and overburden pressures. Figure 2.2 shows the SP-RC-Pu surface for the case of no overburden pressure.

Rieke et al. (1983) determined the segregation potential of 34 artificially prepared soil mixtures. The mixtures consisted of 80-95% sand with varying amounts of silt and montmorillonite, poorly crystallized kaolinite or well crystallized kaolinite. Prior to freezing, the samples were consolidated one dimensionally to 50 kPa. The soils were tested under zero applied pressure using a warm side temperature of 1°C. It is noted that the calculation of segregation potential is made when the system is not at steady state. This may affect the value of segregation potential.

Jessberger and Ebel (1984) performed laboratory freezing tests on a silt. The silt was compacted to standard proctor density at the optimum moisture content. The cold side temperature was varied for different tests, but kept constant during each test. The warm side was kept constant at a temperature of about 5°C for two sets of tests and about 3.5°C for a third set of tests. Samples were tested under applied pressures of 23 kPa or 100 kPa.

The data can be interpreted in terms of segregation potential by considering the frost heave rate and the temperature gradient in the frozen fringe during the steady state portion of the experiment. The frost heave rate includes heave due to freezing insitu water and heave due to water intake. It can be argued that the heave due to insitu water is small since the tests reach steady state conditions after a short period of time. The temperature gradient in the frozen fringe was estimated using the temperature gradient in the frozen soil and the relation between the frozen soil and frozen fringe temperature gradient. This relation is developed in chapter 4. An estimate of the gradient in the frozen soil was made by dividing the frost penetration by the cold side temperature. The temperature distribution the authors presents for one test shows this approximation to be valid.

Both the segregation potential and the soil properties derived from the data reported by Jessberger and Ebel can be considered reliable, however all the tests have been conducted using a relatively high warm side temperature. This causes an increase in the unfrozen soil length, which may result in a high suction at the frost front. This produces a low segregation potential as discussed in Section 2.2.2.

Knutsson et al. (1985) determined the segregation potential for silty sands and clayey silts from full scale insitu frost heave tests, a large scale laboratory test and a freezing cell test. Nine insitu tests were conducted. The water table at the sites varied from 1.0 m to 1.8 m below the surface; however the suction at the frost front was small, typically between 0 and 5 kPa. The temperature gradient in frozen fringe was estimated from thermistors near the frost front. The thermistors were placed 0.33 m apart. No mention is given whether temperature readings from the warm side or cold side are used.

In summary it is noted that all of the above soils have not been tested using identical procedures. Variations in testing procedures result in the following possible errors.

1. The suction at the frost front cannot be calculated in all cases, and it varies from case to case due to differing warm side temperatures and unfrozen soil permeability.
2. Sample preparation is not consistent for all cases, which results in different soil fabrics.
3. Experimental errors are present in each case and may be different from study to study.
4. Soil properties are variable throughout the soil profile in the field tests.
5. Soil properties are not reported in all cases.

These factors will influence any correlation between the soil properties and calculated or measured segregation potential.

Figures 3.1 and 3.2 show how the segregation potentials of all these soils are related to the percentage of fines (<0.074 mm) and the percentage of clay (<0.002 mm)in the soil. Figure 3.1 shows that there is little correlation between segregation potential and percentage of fines. Soils with 5% fines and 100% fines can have equal segregation potentials.

Figure 3.2 demonstrates that there is a correlation between percentage of clay and segregation potential. This is especially apparent if soils with a specific type of mineralogy are examined, for example silty sand and kaolinite. It should be noted that a mixture of sand and silt, with no clay has a segregation potential as high as 100×10^{-5} m²/s°C. Rieke proposed that segregation potential was inversely porportional to the activity of the fine fraction and increased with the amount of fines in the soil. Thus the segregation potential could be correlated to the Atterberg Limits and grain size. He called this relation the fines factor, R_f.

$$R_f = \frac{(\%\text{fines})(\%\text{clay sizes in the fine fraction})}{\text{liquid limit of the fine fraction only}} \qquad 3.1$$

Rieke et al. (1983) defined the "%fines," as the amount of material passing the #200 sieve and the "%clay sizes in the fine fraction," as the amount of material that is smaller than .002 mm divided by the amount of material that passes the #200 sieve. The "liquid limit of the fine fraction" is the liquid limit of the material that passes the #200 sieve. It should be noted that this definition of liquid limit differs from the standard definition of liquid limit, (ASTM-D-423) which states that the liquid limit test is carried out on the material which passes the #40 sieve.

Seed et al. (1964) shows that the liquid limit of a soil is linearly related to the amount of clay in the soil. Using this relation R_f can be rewritten as:

$$R_f = \frac{(\%<0.002\ \text{mm}) \times (\%<0.074\ \text{mm}) \times 100}{(\%<0.425\ \text{mm}) \times \text{Liquid Limit of the soil}} \qquad 3.2$$

Figure 3.3 shows segregation potential versus the fines factor. If the soils that Rieke tested are examined it appears that there is a correlation between segregation potential and the fines factor with segregation potential increasing with the fines factor. As mentioned the soils Rieke tested were all sandy soils. To make the correlation more applicable the soils previously discussed are shown on Figure 3.3

The principle behind R_f states that segregation potential increases with the fines factor. For the lower values of R_f this holds true. For the soils with R_f above 30 there is a considerable amount of scatter in the data and segregation potential appears to decrease with an increase in R_f. This introduces some uncertainty in the use of R_f to estimate segregation potential.

It was suggested in the previous section that the segregation potential may be related to the thickness of the unfrozen water. The unfrozen water results from the surface activity of the water. The liquid limit of a soil also results from the surface activity of a soil. It is proposed that the thickness of the unfrozen water is related to the thickness of the water around the clay particles at the liquid limit. The liquid limit is an arbitrary measurement of the surface activity of the soil. An estimate of the thickness of adsorbed water at the liquid limit is made by dividing the liquid limit by the specific surface area of the soil. The segregation potential would therefore be a function of the thickness of the unfrozen water films in the frozen fringe and the percentage of clay which dictates the amount of unfrozen water films. These properties are described by the following relation.

$$SSF = (LL/SSA) \times \text{percent clay} \qquad 3.3$$

where

SSF = specific surface factor.

LL = liquid limit of the soil

SSA = specific surface area of the soil

The data of Rieke et al. (1983) was interpreted in terms of SSF. Figure 3.4 shows that a correlation between SSF and SP_0 does exist for these soils.

It is difficult to correlate the soils of table 3.1 using equation 3.3 since no specific surface data exists for any of these soils. The specific surface area of the soils in table 3.1 can be estimated from the activity of the soil as described by Grabowka-Olszewska (1970). It is assumed that the clay mineralogy in the soils consist of kaolinite, illite and montmorillonite. SP_0 vs. SSF for these soils using this method of estimating SSF are shown in Figure 3.5. There is a large amount of scatter in the data; however, there is an overall trend to an increasing value of SP_0 with SSF.

If the data of Figure 3.5 is combined with Rieke's data (Figure 3.4) the correlation is less convincing (Figure 3.6). Both the SP_0 vs R_f and the SP_0 vs SSF correlations have two distinct sets of data. It is uncertain whether this lack of comparability is caused by the different testing methods or by the difference in soils. The soils Rieke tested are composed mainly of sands whereas the soils of table 3.1 are composed mainly of silts and clays. The sandy soils have larger segregation potentials than the fine grained soils. Further work is required to determine if this conclusion is valid or if it is just a result of the data used in this study.

3.3.1 Summary

The attempt to correlate SP_0 to soil properties has been unsuccessful in defining a definite relation between SP_0 and soil properties, but some conclusions may be drawn from the data presented.

Segregation potential is related to the percentage of clay in a soil. The relationship depends on the clay mineralogy of the soil which influences the thickness of the unfrozen water films and thus the permeability of the frozen fringe. The percentage of fines also may influence the segregation potential, however it is not as significant as the percentage of clay. Rieke et al. (1983) showed that only a few percent clay is required to produce a segregation potential that may cause extensive frost heave. Rieke et al. (op cit.) also showed that a soil with 10% silt and no clay had a $SP_0 = 29 \times 10^{-5}$ mm²/s°C, which could be potentially dangerous in certain climatic conditions.

There appears to be a correlation between SP versus Rf, and SP versus SSF for the sandy soils that Rieke et al. (1983) has tested. However, to establish a reliable relationship between segregation potential and soil properties, a testing program is required to examine a full range of soils. Research should also be carried out to establish the influence of soil structure on segregation potential. This is especially important since it defines the best method to prepare samples for laboratory testing.

At the present time, the best method of estimating the segregation potential of a soil is by conducting a frost heave test. If this is unavailable, the R_f vs SP_0 (Rieke et al. 1983) can provide a possible range of SP_0 for sandy soils. Due to lack of data on fine grained soils no general correlation can be suggested. The upper limit of SP_0 for the fine grained soils examined is 300×10^{-5}mm²/s°C.

3.4 Comparison of Frost Susceptibility Classifications

Although the applications of the present frost susceptibility classifications are limited, they should not be overlooked since the classifications have been developed based on many years of experience. To compare these frost susceptibility classifications to the findings of the previous section it is desirable to define a point between a frost susceptible soil and a non-frost susceptible soil using the data presented in the previous section.

It was found that a soil with 5% silt and no clay had no segregation potential. A soil with 10% silt and no clay had a segregation potential. The addition of small amounts of clay to the soil with 5% fines caused the segregation potential of the soil to increase dramatically (Rieke et al, 1983). For comparison purposes the dividing line between a frost susceptible soil and a non-frost susceptible soil will be taken as 5% silt and no clay within a soil. A highly frost susceptible soil is a soil with 5% fines, including 2% clay

3.4.1 Common Frost Susceptibility Classifications

Chamberlain (1981) presents a summary of frost susceptibility classifications used throughout the world. Frost susceptibility of soils has been defined by particle size tests, pore size tests, soil/water interaction tests, soil/water/ice interaction tests and frost heave tests. The most common classifications are based on particle size distribution and the frost heave test results.

The first widely recognized particle size classification was described by Casagrande (1931). This requires the determination of the grain size distribution and the coefficient of uniformity. The criteria states that for nonuniform soils frost heave may be expected when the percentage of grains smaller than 0.02 mm exceeds 3% and in the case of very uniform soils (Cu<5), exceeds 10%.

Casagrande also proposed a guideline for estimating frost susceptibility of soils with the use of the Unified Soil Classification System. This is very similar to the U.S. Army Corps of Engineers (1965) criteria.

The U.S. Army Corps of Engineers have reported the results of hundreds of frost heave tests and derived a frost heave susceptibility classification. It is based on Casagrande's system (the amount finer than 0.02 mm). The frost heave tests were performed using a constant frost penetration rate. Chamberlain (1981) presents a figure showing the zones in the classifaction system. There is a considerable range of degree of frost susceptibility within individual soil groups.

3.4.2 Criteria for Frost Susceptible Soils in Canada

Various regulatory bodies in Canada have specified criteria for frost susceptible soils. Following are the criteria used thoughout Canada.

Alberta

The U.S. Army Corps of Engineers (1965) grain size criteria are used for subgrade soils with a Plasticity Index (PI) less than 12. Clays with a PI between 12 and 25 are considered to have medium frost susceptibility and clays with PI greater than 25 have low frost susceptibility. Base and subbase materials are non frost susceptible if less than 10% is finer than 0.074 mm and PI<5-6%. (Johnson et al., 1975).

Canadian Department of Transport

The Canadian Department of Transport use a zoned textural classification (Armstrong and Csathy, 1963). Chamberlain (1981) presents a figure showing the grain size distribution for each textural classification. A soil with 15% of the material less than 0.074 mm is considered non frost susceptible.

Canadian National Parks

All materials with 36% of the soil smaller than 0.074 mm are frost susceptible and are not allowed within 0.9 m of pavement. Clay soils with PI greater than 11 are also frost susceptible if they lie within 1.5 m of pavement (Armstrong and Csathy, 1963).

Manitoba

Soils with less than 20% clay and greater than 60% silt and sand are classified as frost susceptible. Soils with 20-30% clay may be frost susceptible (Armstrong and Csathy, 1963).

New Brunswick

Soils with greater than 50% silt, gravels with 6-8% silt and clay loams and loam tills with mica in small sizes (<0.074 mm) are classified as frost susceptible (Armstrong and Csathy, 1963).

Newfoundland

Frost Susceptibility	% Grains <0.074 mm
None	0 - 6
Moderate	6 - 12
High	>12

After Armstrong and Csathy (1963).

Nova Scotia

Frost Susceptibility	% Grains <0.074 mm
None	0 - 10
Moderate	10 - 30
High	>30

After Armstrong and Csathy (1963).

Ontario

According to Townsend and Csathy (1963) -

Frost Susceptibility	Amount of Silt	Amount of Very Fine Sand & Silt
None	0 - 40	0 - 45
Slight-Medium	40 - 50	45 - 60
High	50 - 100	60 - 100

More recently Johnson et al. (1975) reported that the Ontario Department of Highways states that soils with 0-8% of particles smaller than 0.074 mm and PI of zero are non frost susceptible.

Quebec

According to Armstrong and Csathy (1963)

Frost Susceptibility	Grains <0.074 mm	Amount of Silt & Fine Sand
None	0 - 10	0 - 20
Moderate	10 - 30	20 - 40
High	>30	>40

Johnson et al. (1975) reports that Quebec classifies the soil as frost susceptible when more than 10% of the particles are smaller than 0.074 mm and more than 3% are smaller than 0.053 mm.

Saskatchewan

Johnson et al. (1975) reports that Saskatchewan classifies soils mainly by experience. Base materials with 7-10% of the particles smaller than 0.074 mm are considered non-frost susceptible as are subbase materials with 0-20% smaller than 0.074 mm.

3.4.3 Summary

The dividing line between frost susceptible soils and non-frost susceptible soils proposed from the SP_0 data was established to be 5% fines with no clay particles. A highly frost susceptible soil is a soil with 5% fines, including 2% clay.

This dividing line between frost susceptible soils and non frost susceptible soils is similar to the classifacations used by Newfoundland, Nova Scotia, Ontario Department of Highways, Quebec, Canadian Department of

Transport, and U.S. Army Corps of Engineers, Saskatchewan, Alberta and the Casagrande classification. This supports the findings in the previous section that only a small amount of fines is necessary to cause a soil to be frost susceptible. Some of these organizations use 10% fines as the dividing point between frost susceptible and non-frost susceptible soils. This study has shown that a soil with less than 10% fines can have a high segregation potential.

The frost susceptiblity classifications used by Manatoba, New Brunswick, and Canadian National Parks are not conservative. They allow as much as 60% silt before the soils are considered frost susceptible. These classifications can lead to situations where frost heave damage will occur. It is reccommended that these classifications be updated.

The main distinction between the present classifications and the findings of the previous section is the criteron used to judge the degree of frost susceptibility. Most of the frost susceptibility classifications use the amount of silt as the criterion. It was found that the amount of clay had a much greater influence on the frost susceptibility of a soil than the amount of fines.

Soil	Reference	%fines	%clay	PL	LL	Activity	Comments	SPo 10-5 mm2/sC
Devon Silt (NS)	Konrad (1980)	97	35	19.8	46.1	0.75	Remolded from a slurry, Reconsolidated to 200 KPa.	160
Devon Silt (S)	Konrad (1980)	100	32	18.0	39.0	0.66	" " "	130
Fairbanks Silt	Aitken (1974)	98 98	15 5	14.1 1.8	48.7 31.2	2.3 5.9	Insitu test. Soil properties variable through profile.	63
Compacted Silt	Jessberger and Ebel (1984)	85	15	22.6	29.9	0.49	Remolded to Proctor at OMC. High warm side temperature.	45
Agassiz Silt	Knutsson et al. (1985)	100	16	22.0	28.0	0.38	Large scale lab test. γ_d = 18.5 KN/m3	307
Ojeby Silt	Knutsson et al. (1985)	100	5	-	25.0-31.0	-	Freezing cell test.	150
New Hampshire Silt	Loch and Kay (1978)	93	10	20.5	26.5	0.5	wc = 45%. γ_d = 1.46 g/cm2.	70

Table 3.1 Soils with segregation potential information.

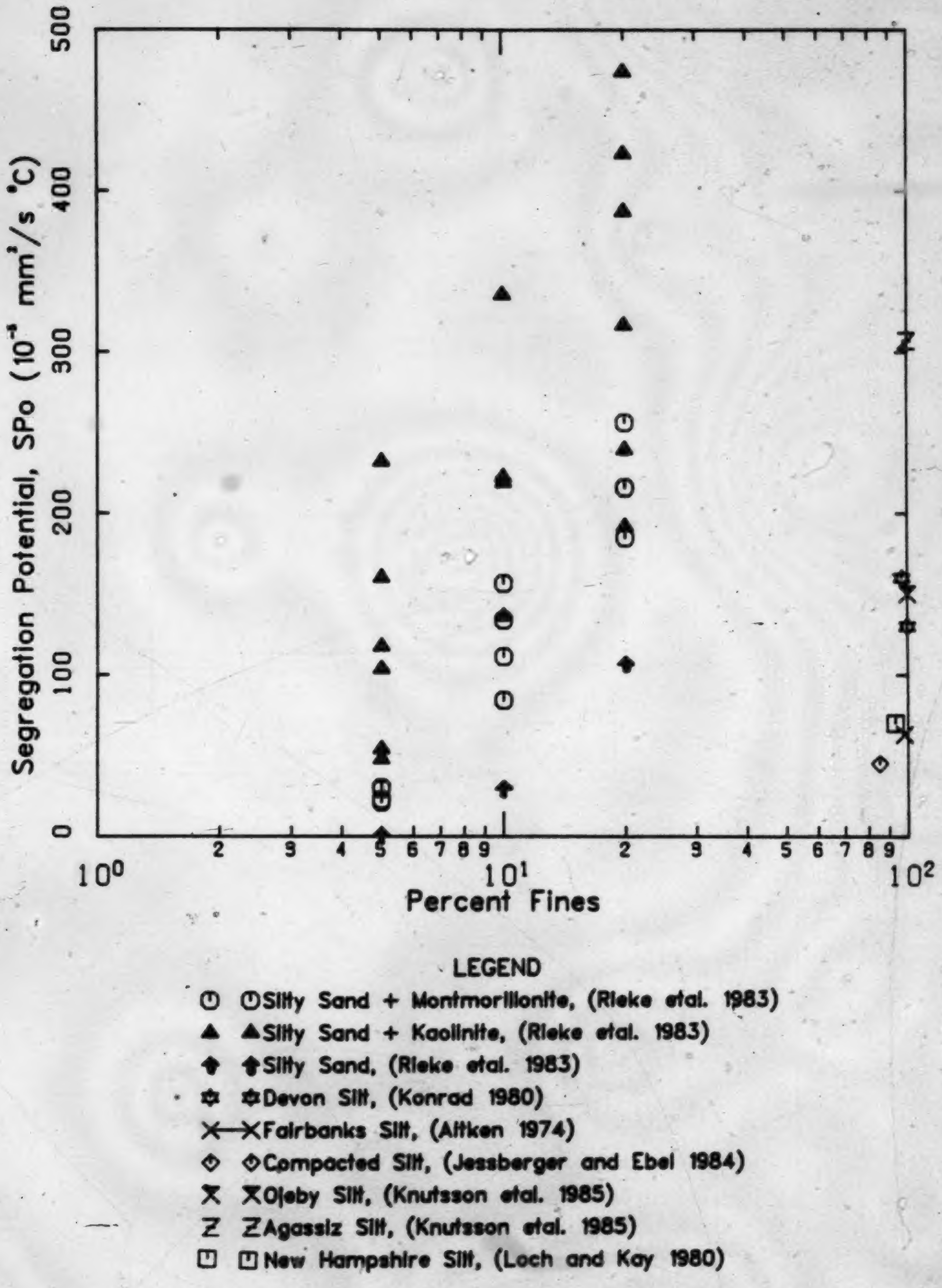


Figure 3.1 Segregation potential versus percent fines.

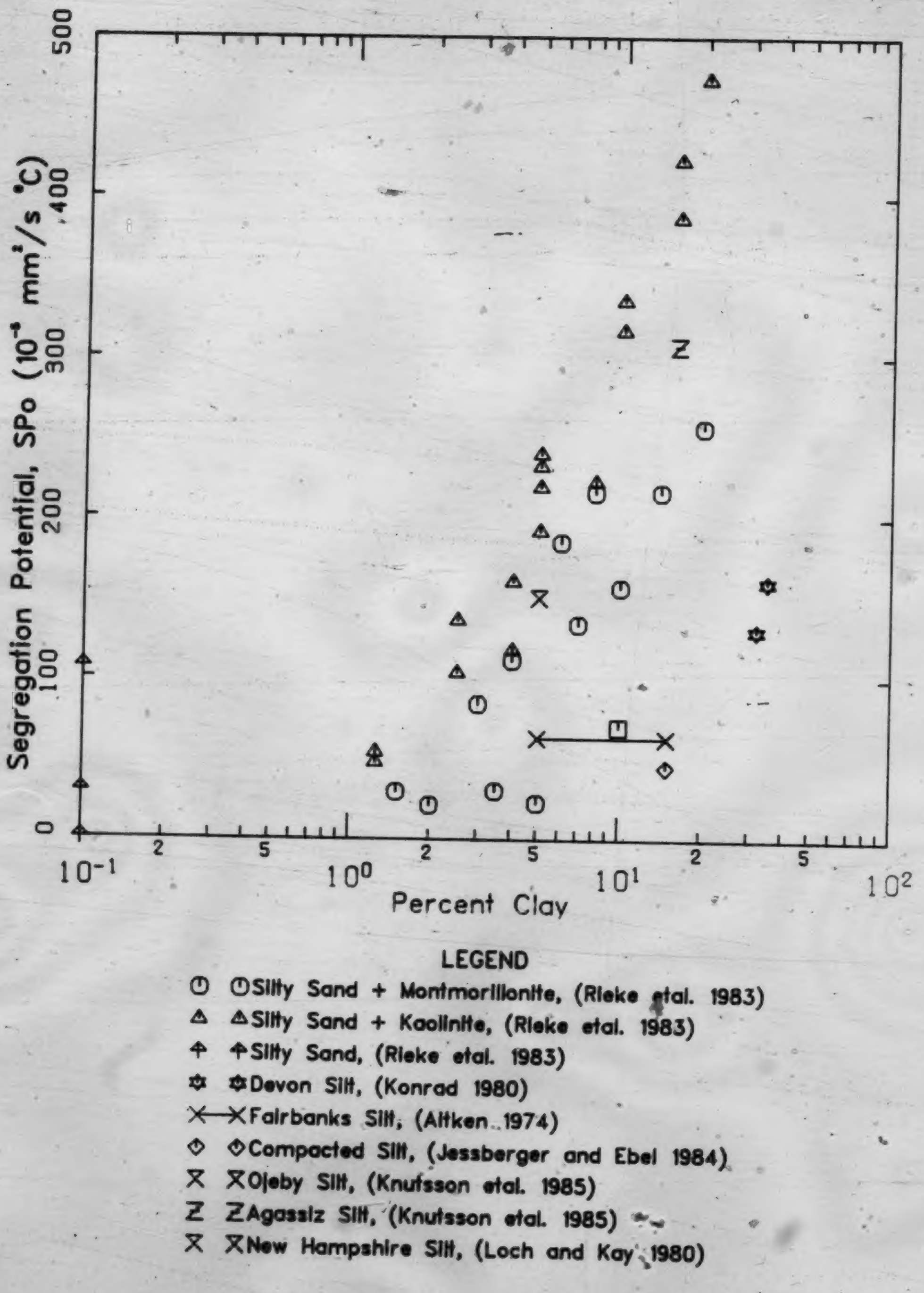


Figure 3.2 Segregation potential versus percent clay.

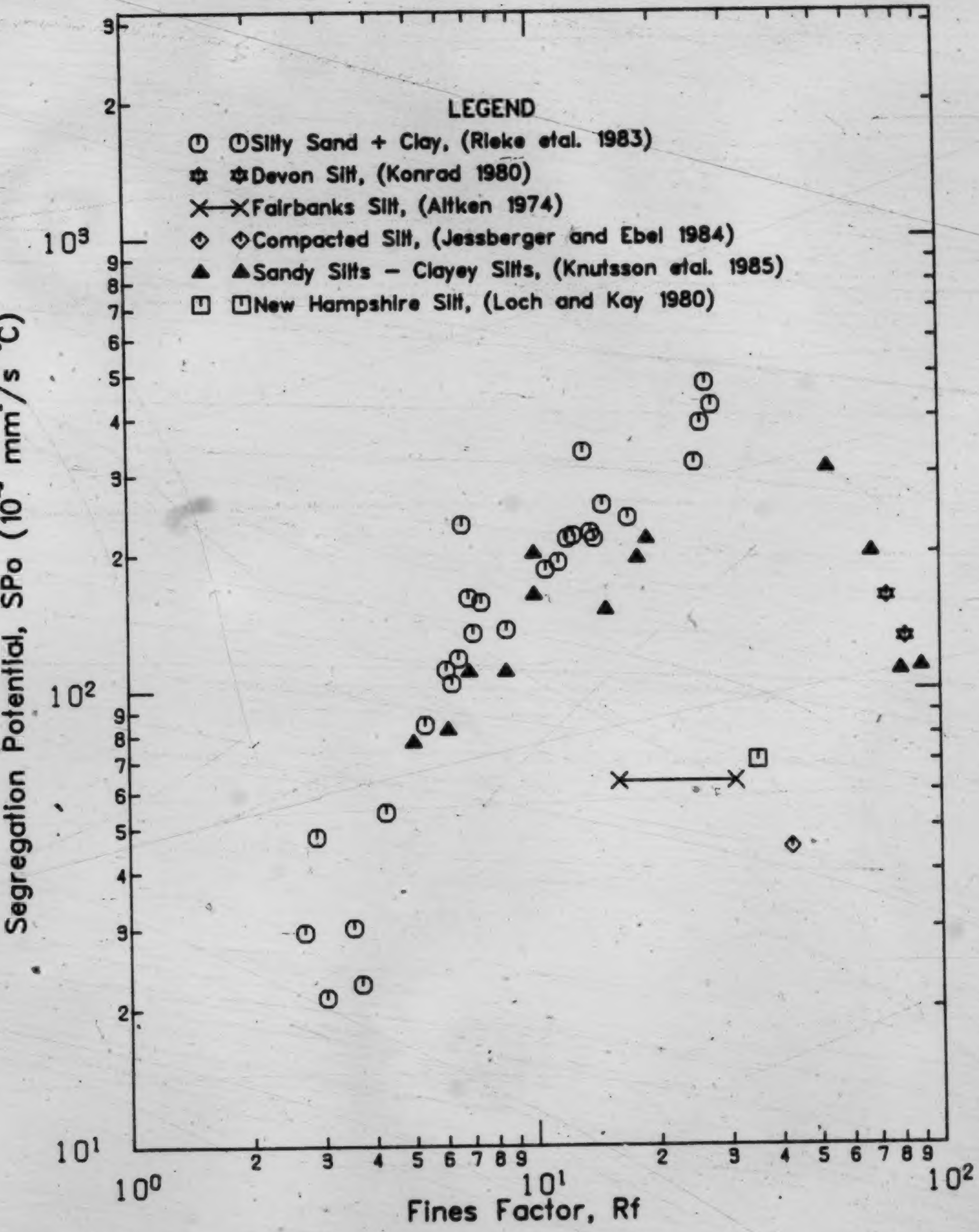


Figure 3.3 Segregation potential versus fines factor, R_f.

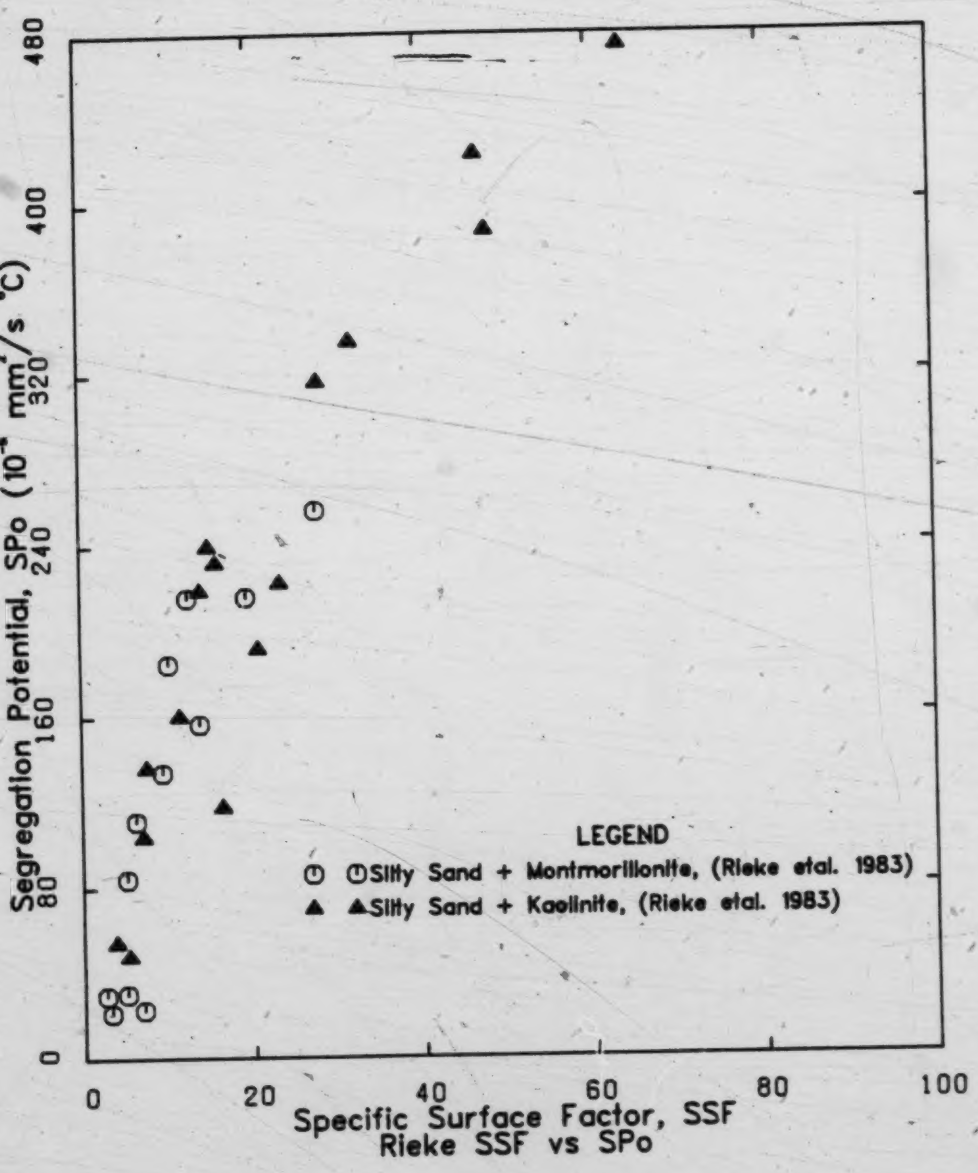


Figure 3.4 Segregation potential of Rieke et al (1983) versus specific surface factor, SSF.

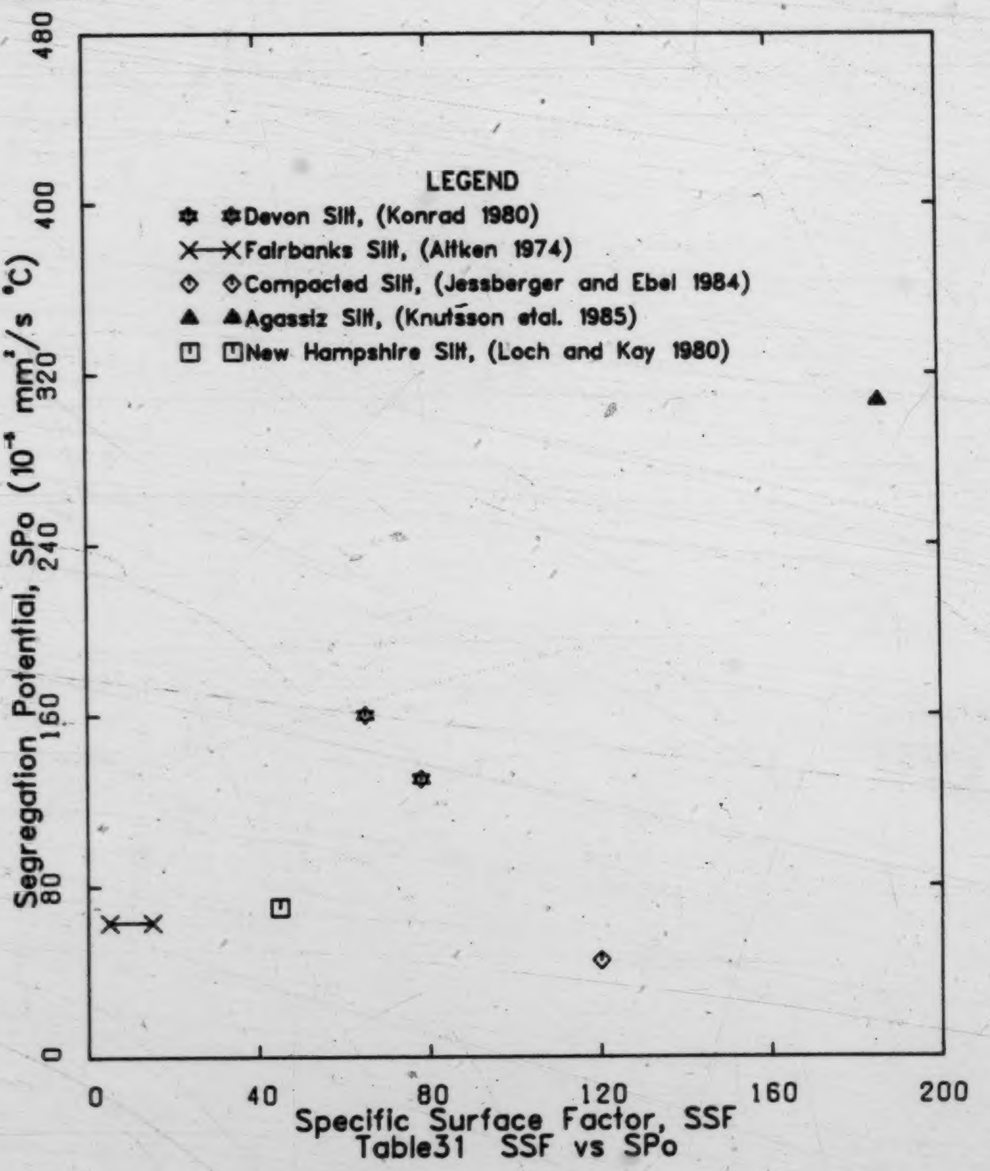
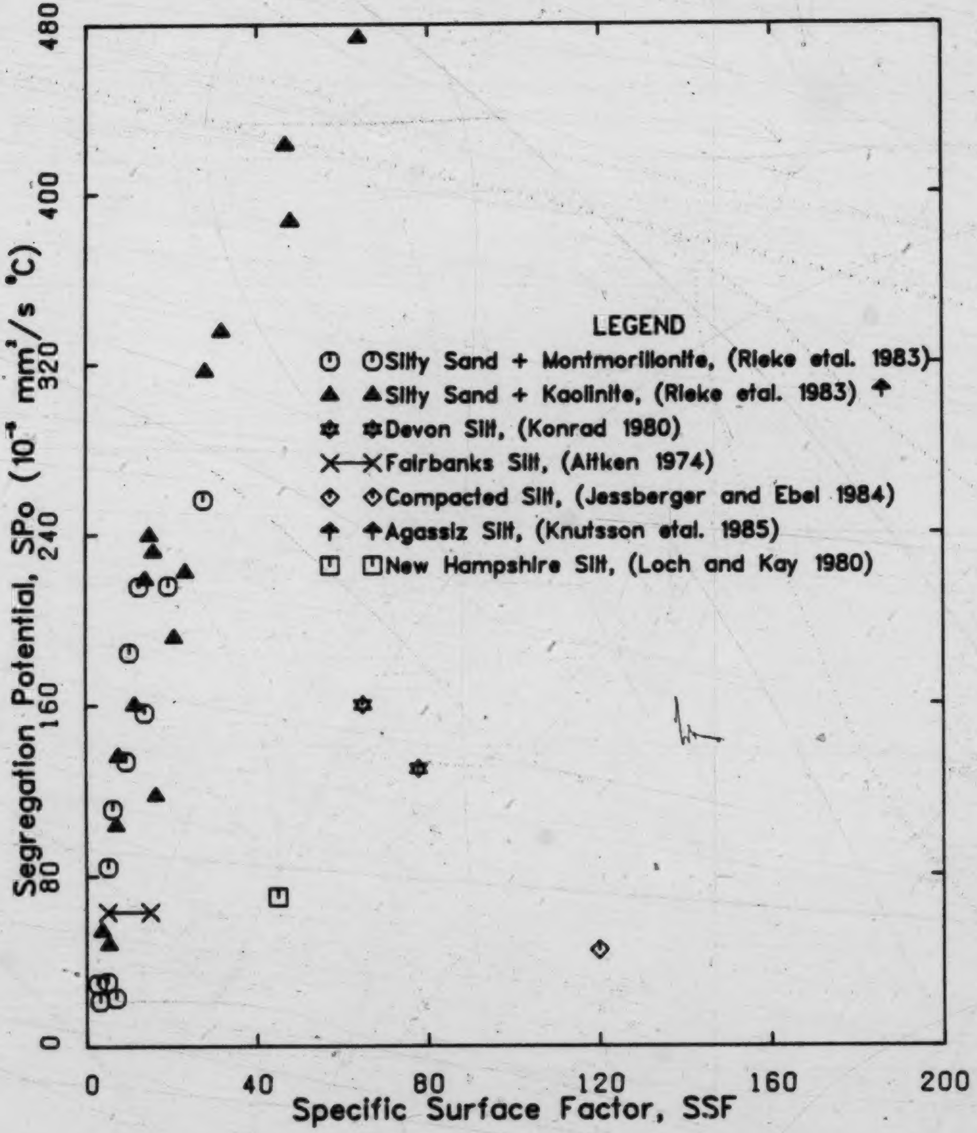


Figure 3.5 Segregation potential versus specific surface factor, SSF.



Combined SSF vs SPo

Figure 3.6 Segregation potential versus specific surface factor, SSF.

4.0 ESTIMATING THE MAGNITUDE OF FROST HEAVE

As discussed in Chapter 2 the magnitude of frost heave is a function of the segregation potential and the temperature gradient within the frozen fringe. The segregation potential depends on the soil properties, rate of cooling, suction at the frost front, and overburden pressure at the ice lens. The temperature gradient in the frozen fringe is a function of the boundary conditions and the thermal properties of the soil water-ice system.

A one dimensional model has been developed to include all of these input parameters for the freezing system. It is then demonstrated that the model can be simplified in order that the magnitude of frost heave may be estimated for a field test. In Chapter five the model is extended to a case of two dimensional heat flow.

4.1 One Dimensional Model

The methodology of the one dimensional model follows the development by Konrad (1980) for estimating heave during unsteady heat flow. Konrad's model accurately estimated heave from laboratory freezing tests. Modifications were made to this model to make it applicable to the field situation. The flow chart in Figure 4.1 illustrates the procedure used. Example input and output files and the Fortran code for the model are found in Appendix B.

The program proceeds in an incremental manner. The nonsteady state heat flow is solved by a finite difference approach described by Crank and Nicholson (1947). The equations generated are solved using Gaussian elimination. Heat flow is solved separately in the frozen and unfrozen portions of the soil.

All of the intake water is assumed to change phase at the base of the ice lens. The phase change of the insitu water is lumped at the boundary of the frozen fringe and the unfrozen soil. The temperature gradient in the frozen fringe is determined by considering the heat flow at the boundary of the frozen fringe and the frozen soil. Balance of heat flow at the boundary of the frozen fringe and the frozen soil leads to the following expression.

$$k_{fr}(\partial T/\partial z)_{fr} - k_{ff}(\partial T/\partial z)_{ff} = V(t)\cdot L \qquad 4.1$$

where

k_{fr} = thermal conductivity of the frozen soil
k_{ff} = thermal conductivity of the frozen fringe
$V(t)$ = velocity at time t
L = latent heat of fusion of water
T = temperature
z = depth

The velocity of the intake water can be expressed as:

$$V(t) = SP(t)\cdot(\partial T/\partial z)_{ff} \qquad 4.2$$

Combining equations 4.1 and 4.2 results in the following expression for the temperature gradient in the frozen fringe.

$$(\partial T/\partial z)_{ff} = [k_{fr}(\partial T/\partial z)_{fr}]/[SP(t)\cdot L + k_{ff}] \qquad 4.3$$

It should be noted that this expression differs from the relation used in the Konrad model for simulation of laboratory freezing tests. Konrad's model does not include the effects of the phase change of the intake water in determining the temperature gradient in the frozen fringe. To verify that the model is still valid with the phase change considered, a freezing test is analyzed with and without the phase change taken into account. The results of this analysis are illustrated in Figure 4.2. The predicted heave closely reproduces the measured experimental heave in the case where the heat released from the phase change is included in the model.

At this point the computer program determines the rate of cooling within the frozen fringe. This is determined by the expression:

$$dT/dt = \frac{(\text{grad } Tf(t+dt) \cdot (dz + d(t)/2) - Ts/2}{dt} \qquad 4.4$$

where

dz = change in frost penetration depth

d(t) = thickness of the frozen fringe at time t

grad Tf(t+dt) = temperature gradient in the fringe at time t+dt

The intake velocity is calculated using equation 4.2, with the segregation potential being determined from the SP-RC-Pu surface (Figure 2.2). However, the intake velocity must also obey Darcy's law through the unfrozen soil. If it is assumed that the water pressure at the water source is zero, the velocity through the unfrozen soil can be expressed as:

$$V = Ku \cdot [Pu/lu] \qquad 4.5$$

where

Ku = permeability of the unfrozen soil

Pu = suction at the frost front

lu = distance between the water source and the frost front

Compatibility must be satisfied between equation 4.2 and 4.5. This is accomplished by an iterative procedure, solving for the velocity and segregation potential as a function of the suction at the frost front.

The segregation potential is a function of the overburden pressure. As the frost front penetrates into the ground, the overburden pressure at the ice lens increases due to the weight of the frozen soil above it. Unfortunately, the SP-RC-Pu surface has only been experimentally determined for the case where the overburden pressure is equal to zero.

The overburden pressure due to the weight of the frozen soil is small; therefore an attempt has been made to use the SP-RC-Pu surface of the case for zero overburden pressure with a reduction applied to the calculated SP for the effects of overburden pressure. The segregation potential was reduced due to the overburden pressure using equation 2.10. The value of "a" is taken as the value of SP determined from the SP-RC-Pu surface for the case of no overburden pressure.

$$SP_x = SP\cdot\exp(-b\cdot P_e) \qquad 4.6$$

where

SP_x = Segregation potential including effects of overburden pressure

SP = Segregation potential determined from the SP-RC-Pu surface for $P_e = 0$

P_e = the magnitude of overburden pressure

A laboratory freezing test with an overburden pressure of 45 kPa conducted by Konrad (1980) was used to verify the accuracy of Equation 4.6. The value of "b=8.95" experimentally determined for Devon Silt at Pu=0 was used in the analysis. The predicted heave simulated the actual heave with a high degree of accuracy. This is illustrated in Figure 4.3. It is concluded that this method of accounting for the overburden pressure is sufficient for engineering purposes until more detail information is available on the pressure influence on the SP-RC-Pu surface.

As demonstrated in Chapter 3, the range of segregation potential for different soils is great, and the number of soils with accurately measured segregation potential data is limited. Some assumptions had to be made regarding the SP-RC-Pu surface for soils other than Devon Silt. For this analysis it was assumed that all soils will have the same shape of SP-RC-Pu surface as Devon Silt. The magnitude of SP was scaled by a constant amount for all situations of Pu and RC. The magnitude of segregation potential was scaled by the following relationship.

$$SP_F = \frac{SP_o}{SP_{DO}} \cdot SP_D \qquad 4.7$$

where

SP_F = Factored segregation potential

SP_o = Segregation potential of the soil being analyzed at the formation of the final ice lens.

SP_{DO}= Segregation potential of Devon Silt at the formation of the final ice lens.

SP_D = Segregation potential of Devon Silt determined from its SP-RC-Pu surface.

The frost penetration was determined by considering the balance of heat flow into and out of the frozen fringe. This led to the expression:

$$dz = dt(k_{fr}(\partial T/\partial z)_{fr} - k_u(\partial T/\partial z)_u - V \cdot L)/(\epsilon \cdot n \cdot L) \qquad 4.8$$

where

dz = increment of frost penetration

dt = time increment

ϵ = fraction of insitu water that freezes

n = porosity of soil

k_{fr} = thermal conductivity of the frozen soil

k_u = thermal conductivity of the unfrozen soil

Frost heave consists of insitu heave and segregational heave. The total heave is the addition of both the insitu heave and the segregational heave. The insitu heave results from the expansion of the pore water when it freezes. If the soil is saturated the insitu heave for the specific time increment is:

$$dh_i = 0.09 \cdot \epsilon \cdot n \cdot dz \tag{4.9}$$

where

dh_i = increment of insitu heave

0.09 = the volumetric expansion that occurs when water freezes

ϵ = fraction of insitu water that freezes

n = porosity of the soil

dz = increment of frost penetration

If the soil has a degree of saturation less than 90% no insitu heave will occur. This is due to the fact that the water will expand into the air voids instead of displacing the soil.

The segregational heave is due to moisture transfer in the frozen fringe. The magnitude of segregational heave is composed of the volume of intake water and the expansion that occurs when the water freezes.

$$dh_s = (V + 0.09 \cdot V) \cdot dt \tag{4.10}$$

where

dh_s = increment of segregational heave

V = intake velocity

dt = time step

The total heave is:

$$dh_t = dh_i + dh_s$$

The program proceeds incrementally solving and accumulating the segregational heave and the total heave.

4.2 Analysis Parameters

The amount of heave obtained from the analysis is dependent on the input parameters, the mesh properties and the boundary conditions. The most important input parameters are the depth to the water source, permeability of the unfrozen soil, ground freezing index, segregation potential, and soil type. Each of the above parameters will be discussed separately in the following sections to evaluate their influence on the magnitude of total and segregational heave determined.

4.2.1 Boundary Conditions and Mesh Properties

A sensitivity analysis was conducted for various cold side temperature distributions. Figure 4.4 shows how the length of the freezing season influences the magnitude of heave. The analysis indicates that the magnitude of heave is slightly greater for a shorter freezing period. Figure 4.5 illustrates frost heave during the freezing season for a constant and a sinusoidal temperature distribution. The rate of heave differs; however, the magnitude of heave at the end of the season is approximately equal for both temperature distributions. It is concluded that the temperature distribution is not a critical parameter to determine the magnitude of heave at the end of the freezing season. All subsequent analyses use sinusoidal temperature distributions, as these represent a more realistic freezing season ground surface temperature distribution.

An estimate of the number of freezing days for a particular freezing index was determined by examining temperature distributions for localities in Canada (Boyd, 1973). In the analysis the number of freezing days were 120 days for a freezing index of 500 °C days or less, 150 days for a freezing index greater than 500 °C days and less than 2000 °C days, and 180 days for a freezing index of 2000 °C days and over.

The initial ground temperature distribution is set to a uniform distribution of 4 °C. The influence of the initial ground temperature distribution is examined in Chapter 5 and shows this approximation to be valid.

The depth of the lower mesh boundary surface was chosen so that it had no influence on the amount of heave calculated. The minimum depth was found to be 5 m for a soil with a moisture content equal to or greater than 20%, and 10 m for a soil with a moisture content equal to 10%. The lower boundary was set to a constant temperature distribution of 4° C over the entire freezing season.

The finite difference approach requires that the ground be divided into elements and analyzed in time increments. The number of elements, thickness of the segments, and length of the time steps were adjusted to make the analysis accurate and cost efficient. Segments of an equal length of 25 mm and the time steps of 17 minutes in duration were found to provide good accuracy in all cases.

4.2.2 Input Parameters

4.2.2.1 Water Content and Thermal Properties

A sensitivity analysis was carried out to analyze the effect of different soil types on the magnitude of frost heave. This analysis was concerned with thermal properties and the water content of the soil. The heat capacity was calculated by considering the heat capacity of the various constituents of the frozen and unfrozen soil:

$$C = \gamma_d \, (c_s + c_w \, w + c_i w_i) \qquad 4.11$$

where

γ_d = dry density of the soil

c_s = heat capacity of the soil grains

c_w = heat capacity of water

c_i = heat capacity of ice

w = unfrozen water content

w_i = frozen water content

The thermal conductivity for the frozen and unfrozen parts of the soils was obtained from Kersten's charts presented by Andersland and Anderson (1978). Figure 4.6 shows that the magnitude of heave is relatively insensitive to variations in the value of unfrozen thermal conductivity used in the analysis. The magnitude of heave increases with an decrease in frozen thermal conductivity. Decreasing the frozen thermal conductivity by 20% resulted in a 12% increase in the segregational heave and a 5% increase in the total amount of heave.

Figure 4.7 shows the magnitude of frost heave experienced by different soil types under the same freezing conditions. Table 4.1 describes the properties of these soils. A soil with a high water content experiences a greater amount of segregational and insitu heave than one with a lower moisture content. A soil with a low moisture content experiences a greater frost penetration due to its low latent heat. This results in a lower temperature gradient, which induces a lower magnitude of heave. A soil with a low moisture content also has less insitu heave caused by the expansion of the water within the soil voids.

The analysis included a coarse and a fine grained soil with a water content of 20%. All parameters were held constant except the thermal conductivities of the two soils. The coarse grained soil has a frozen thermal conductivity 42% greater than the fine grained soil. The model predicts that the soil experiences 16% less segregational heave and 20% more insitu heave. The higher thermal conductivity of the coarse grained soil resulted in deeper frost front penetration which resulted in decreased temperature gradients, which leads to a reduction in the magnitude of segregational heave but an increase in the insitu heave. These two mechanisms balance out so there is only a small difference in total heave. Total heave is more sensitive to a change in water content than the frozen thermal conductivity.

4.2.2.2 Suction at the Frost Front

The permeability of the unfrozen soil as well as the distance between the frost front and the water source influence the suction at the frost front. The variation of segregation potential with suction at the frost front is different for different soils, however it has only been experimentally determined for Devon Silt (Konrad, 1980). A soil with a lower segregational freezing temperature will generate a higher suction at the ice lens, therefore the suction at the frost front where the segregation potential goes to zero will also be higher.

The SP-Pu relationship of Devon Silt is used for this study. This introduces some uncertainty in using the results for other soils. However an upperbound solution for the magnitude of frost heave can be made by assuming that the water source is at the ground surface.

As the frost front penetrates below the water source free availability of water is assumed in the calculation. This assumption is justified because the actual intake velocity is small. The rate of intake water is not sufficient to drawdown the aquifer. In a freezing test free availability of water exists when the length of the unfrozen soil is very small. When the length of the unfrozen soil is small the suction at the frost front(Pu) is very close to zero. In the analysis a value of SP is determined from the SP-Pu-Rc curve by assuming Pu is equal to zero. This results in a maximum value for SP which leads to an upper bound value of the frost heave magnitude.

4.2.2.3 Permeability of the Unfrozen Soil

Lambe and Whitman (1969) show that the permeability of sandy clay soils and silty soils can range from 2 x 10^{-6} m/s to 5 x 10^{-12} m/s. Using the relationship between SP-RC-Pu for Devon Silt a sensitivity analysis was conducted to determine the influence of permeability on the magnitude of frost heave. Figure 4.8 shows the results of this analysis. A soil with a permeability less than 10^{-11} m/s experiences virtually no segregational heave until the frost front penetrates below the water source. If a soil has a permeability greater than 10^{-6} m/s the depth to the water source will have very little influence on the magnitude of heave because the suction generated is small.

4.2.2.4 Zone of Saturation Above the Water Table

The permeability of a soil is affected significantly by the degree of saturation. This is important to consider in the field since the soil profile may not be 100% saturated. As water percolates down by gravitational forces to the water table, the only water remaining in the soil pores is water bound to the particles by surface tension and electromotive forces. Figure 4.9 shows degree of saturation variations for some typical soils profiles.

The capillary fringe can be divided into regions of capillary saturation and partial capillary saturation. The region of capillary saturation is almost fully saturated, whereas the zone of partial capillary saturation is only partially saturated. A fine grained soil has a large capillary fringe. The degree of saturation gradually decreases as the distance from the water table increases. A coarse grained soil has a much smaller capillary fringe. The degree of saturation decreases rapidly as distance from the water source increases.

Darcy's law has been shown to be valid for partially saturated soils (Koorevaar et al, 1983). Figure 4.10 illustrates how the permeability is affected by the degree of saturation. A 20% reduction in the degree of saturation results in a reduction in the permeability of one order of magnitude, or greater.

This variation in permeability and degree of saturation is modelled as a two layered system (Figure 4.11). By examining the degree of saturation curves(Figure 4.9) for various soil types, saturation profiles are adopted for this analysis. A higher degree of saturation results in more segregational heave due to a higher water content and a higher permeability. To obtain a conservative value for the magnitude of frost heave a high degree of saturation is assumed for the analysis. It is assumed that a fine grained soil is fully saturated between the water table and 100 cm above the the water table. Above the zone of saturation the soil is 75% saturated. In the zone above the saturated soil the permeability is assumed to be two orders of magnitude lower than the saturated permeability. A coarse grained soil is assumed to have a saturated zone 50 cm above the water table. Above this the soil is 50% saturated. Above the zone of saturation a coarse grained soil has a low water content, which results in a very low permeability. For this reason the unsaturated coarse grained soil is assumed to have a permeability four orders of magnitude lower than it's saturated permeability.

As discussed, the insitu heave is zero in a soil with a degree of saturation less than 90%. Therefore no insitu heave will occur in the unsaturated zones of these soils.

4.2.2.5 Segregation Potential in Partially Saturated Soil

This analysis assumes that segregational heave will occur throughout the soil profile. The segregation potential of a partially saturated soil has never been determined experimentally.

As discussed in Chapter 2, segregation potential is a function of the permeability of the frozen fringe and the driving force at the base of the ice lens. Since most of the boundary water remains in a partially saturated soil, a slight decrease in the degree of saturation will have little influence on the amount of unfrozen water present as adsorbed film on the fine grained soil particles within the frozen fringe. Therefore the permeability of the frozen fringe and the segregational freezing temperature will not be influenced by a slight decrease in the degree of saturation. It is speculated that the segregation potential of a partially saturated soil will nearly equal that of a saturated soil.

4.3 Results of the One Dimensional Analysis

The overall objective of this study is to provide a basis for estimating the amount of frost heave for the design of foundations of unheated structures. To meet this objective, figures are produced from which the magnitude of frost heave can be estimated for varying ground freezing indices, soil types, water table conditions and segregation potentials.

Three soil types are analyzed: a fine grained soil with a high permeability, a fine grained soil with a low permeability and a coarse grain soil. The properties of these soils are described in table 4.2. The fine grained soil with a low permeability has a saturated permeability of 10^{-9} m/s. This is equal to the permeability of Devon Silt. The insitu permeability of many fine grained soils may be higher than this due to cracks and fissures. Therefore the analysis was also carried out for a fine grained soil with the permeability of the saturated soil equal to 10^{-6} m/s. The analysis was also conducted for a coarse grained soil with the permeability of the saturated soil equal to 10^{-5} m/s. Figure 4.12 shows how the permeability of the three soils influences the relationship between heave and the depth to the water source. The fine grained soil with the low permeability experiences very little segregational heave if the water source is more than 250 cm below the ground surface. If the water source is 400 cm below the ground surface the magnitude of segregational heave is reduced by 50% and 65% for the high permeable fine grained soil and the coarse grained soil respectively.

Figures 4.13 to 4.21 illustrate the magnitude of heave these soils will experience for various ground freezing indices and water table conditions. From these figures, the heave for a particular site may be estimated. An upperbound value for magnitude of heave can be obtained by assuming that the water source is at the ground surface.

4.4 Simplified Method of Frost Heave

The model presented for one dimensional frost heave can be simplified by making assumptions about the rate of cooling, suction at the frost front, and the overburden pressure. These assumptions are discussed by Konrad and Morgenstern (1983).

In the field the rate of cooling is very low after the initial freezing period. Typically after the first 15 days of freezing, the cases analyzed have a rate of cooling less than 0.01 °C/hr and after the first 30 days the rate of cooling is less than 0.005 °C/hr.

Rates of cooling of this magnitude are associated with the formation of the final ice lens in laboratory freezing tests (Konrad, 1980). The segregation potential of soil for a particular suction at the frost front does not vary greatly within this range of cooling rates.

If the water table is near the surface or the permeability of the soil is such that high suctions at the frost front are not generated, the suction at the frost front can be taken as equal to zero.

It has been demonstrated that the segregation potential of a soil decreases as the overburden pressure increases. As the frost front penetrates into the ground the overburden pressure at the ice lens increases. The decrease in segregation potential can be accounted for in the simple analysis in two different ways. The first method calculates the overburden pressure and adjusts the segregation potential as the analysis proceeds. A simpler way of accounting for the decreasing segregation potential is by calculating the average overburden pressure during the freezing period. A constant value of the segregation potential is then used throughout the analysis.

As a result of these simplifications the rate of cooling, and the suction at the frost front do not have to be determined through out the analysis and a constant value of segregation potential can be used. Figure 4.22 shows that the simplified method provides results very close to the rigorous calculation of frost heave magnitude.

4.4.1 Field Verification of the Simplified Method

Nixon (1982) applied this simplified method to a field case. A cold plate was installed 3.0 m below the surface and held at a constant temperature of -4° C for a period of 200 days. During the freezing period the temperature profile below the cold plate and the vertical heave of the ground were measured. As the freezing plate was below the water table, there was a constant supply of water to the base of the ice lens.

The temperature gradient used for the analysis was obtained from the measured temperatures in the field. The segregation potential was taken from laboratory freezing Figure 4.23 illustrates the results of the experiment. The general parabolic shape of the heave-time curve was predicted by the simplified analysis. The analysis predicted a heave of 10.4 cm, where as the measured heave was 8 cm. The slight discrepancy between the observed and predicted heaves could have been due to an inaccurate determination of segregation potential. Konrad (1980) noted that there may not have been good control of the warm side temperature during the freezing tests used for this analysis.

The results of this testing program show that it is possible to estimate heave from a simplified method of frost heave prediction. The simplified method is incorporated into a two dimensional model in Chapter 5.

Table 4.1 Properties of soils used for sensitivity analyses.

	COARSE GRAIN SOIL		FINE GRAIN SOIL		
WATER CONTENT %	10.0	20.0	20.0	30.0	45.0
POROSITY	0.21	0.35	0.35	0.45	0.55
FROZEN THERMAL CONDUCTIVITY W/m K	4.00	3.02	2.12	2.04	1.98
UNFROZEN THERMAL CONDUCTIVITY W/m K	3.32	2.46	1.56	1.32	1.11
FROZEN HEAT CAPACITY MJ/m3 K	1.98	2.03	2.03	2.07	2.11
UNFROZEN HEAT CAPACITY MJ/m3 K	2.37	2.68	2.68	2.91	3.14

Table 4.2 Properties of soils used for predicting the magnitude of frost heave.

	COARSE GRAIN SOIL	FINE GRAIN SOIL LOW PERMEABILITY	FINE GRAIN SOIL HIGH PERMEABILITY
WATER CONTENT %	20.0	30.0	30.0
POROSITY	0.35	0.45	0.45
FROZEN THERMAL CONDUCTIVITY W/m K	3.02	2.04	2.04
UNFROZEN THERMAL CONDUCTIVITY W/m K	2.46	1.32	1.32
FROZEN HEAT CAPACITY MJ/m3 K	2.03	2.07	2.07
UNFROZEN HEAT CAPACITY MJ/m3 K	2.68	2.91	2.91
SATURATED PERMEABILITY M/S	10-5	10-9	10-6
UNSATURATED PERMEABILITY M/S	10-9	10-11	10-8
CAPPILLARY SATURATED LENGTH (cm)	50.0	100.0	100.0
SATURATION IN UNSATURATED SOIL (%)	50.0	75.0	75.0

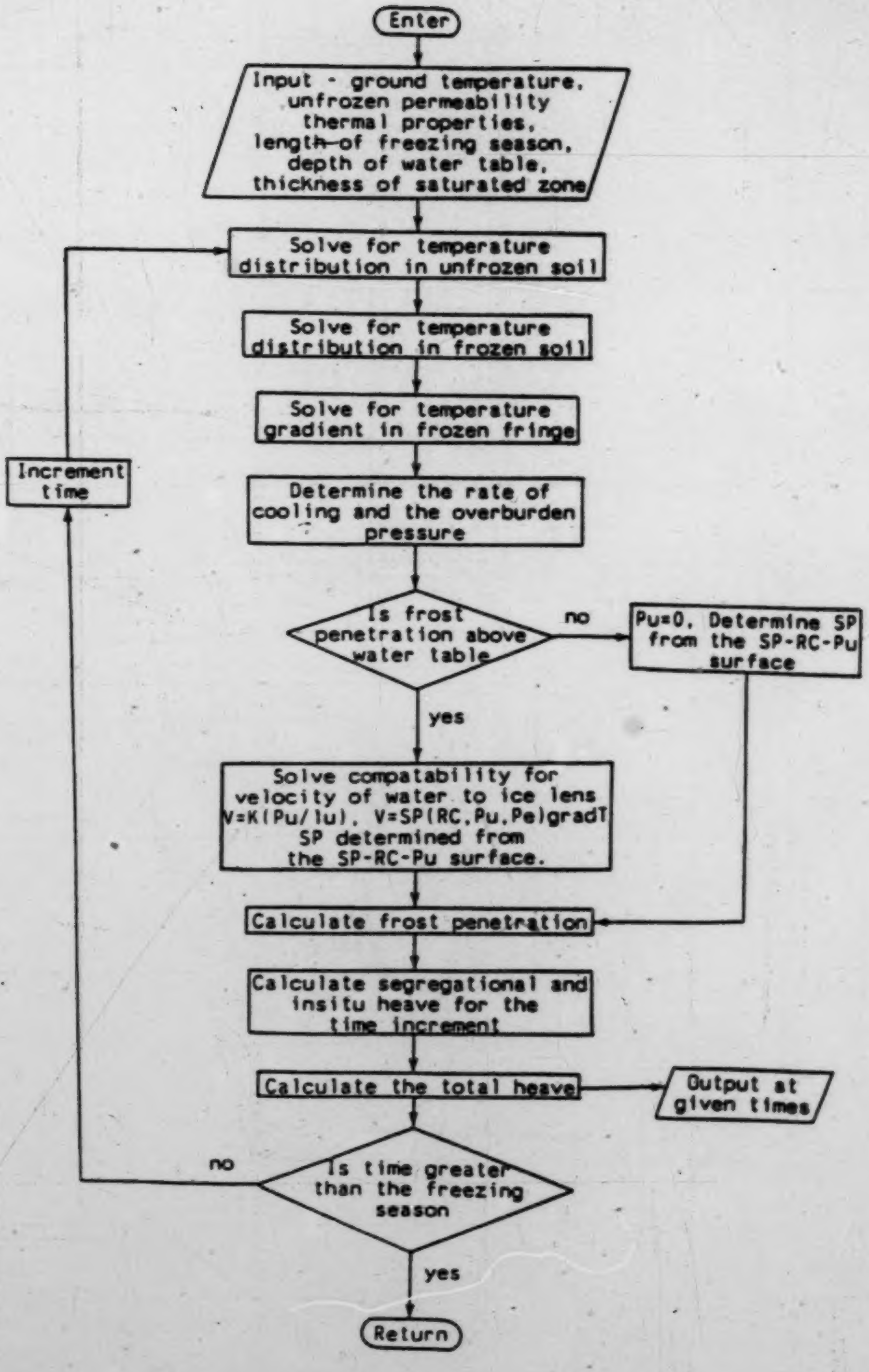

Enter
Input - ground temperature, unfrozen permeability thermal properties, length of freezing season, depth of water table, thickness of saturated zone
Solve for temperature distribution in unfrozen soil
Solve for temperature distribution in frozen soil
Solve for temperature gradient in frozen fringe
Determine the rate of cooling and the overburden pressure
Is frost penetration above water table
no
Pu=0, Determine SP from the SP-RC-Pu surface
yes
Solve compatability for velocity of water to ice lens V=K(Pu/lu), V=SP(RC,Pu,Pe)gradT SP determined from the SP-RC-Pu surface.
Calculate frost penetration
Calculate segregational and insitu heave for the time increment
Calculate the total heave
Output at given times
Increment time
no
Is time greater than the freezing season
yes
Return

Figure 4.1 Flow chart for the one dimensional model.

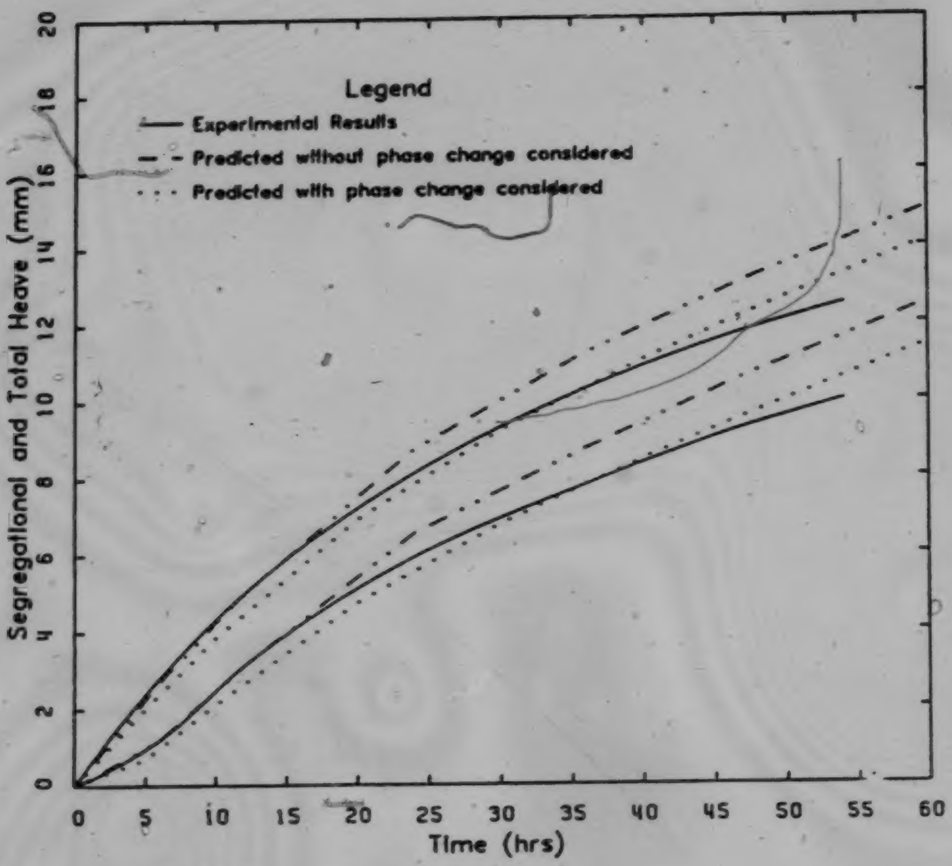


Figure 4.2 Predicted versus actual heave of a freezing test.

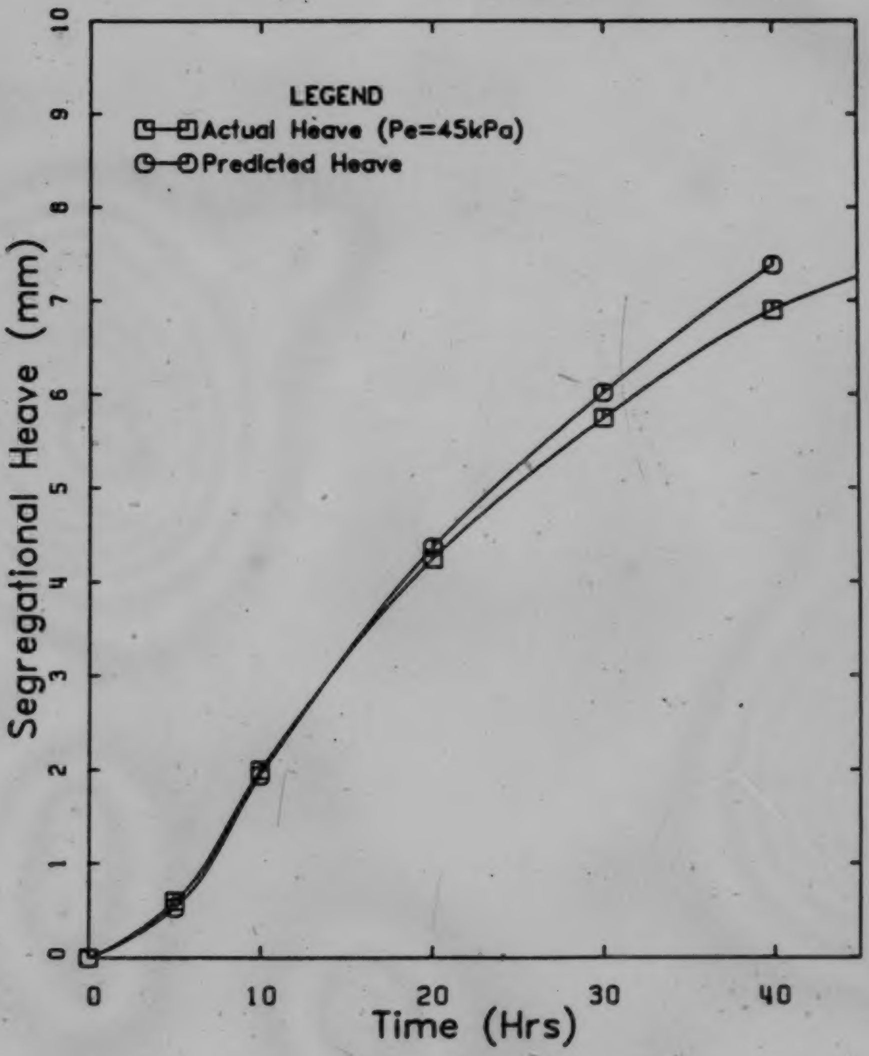


Figure 4.3 Predicted heave versus actual heave for a freezing test Pe=45 kPa.

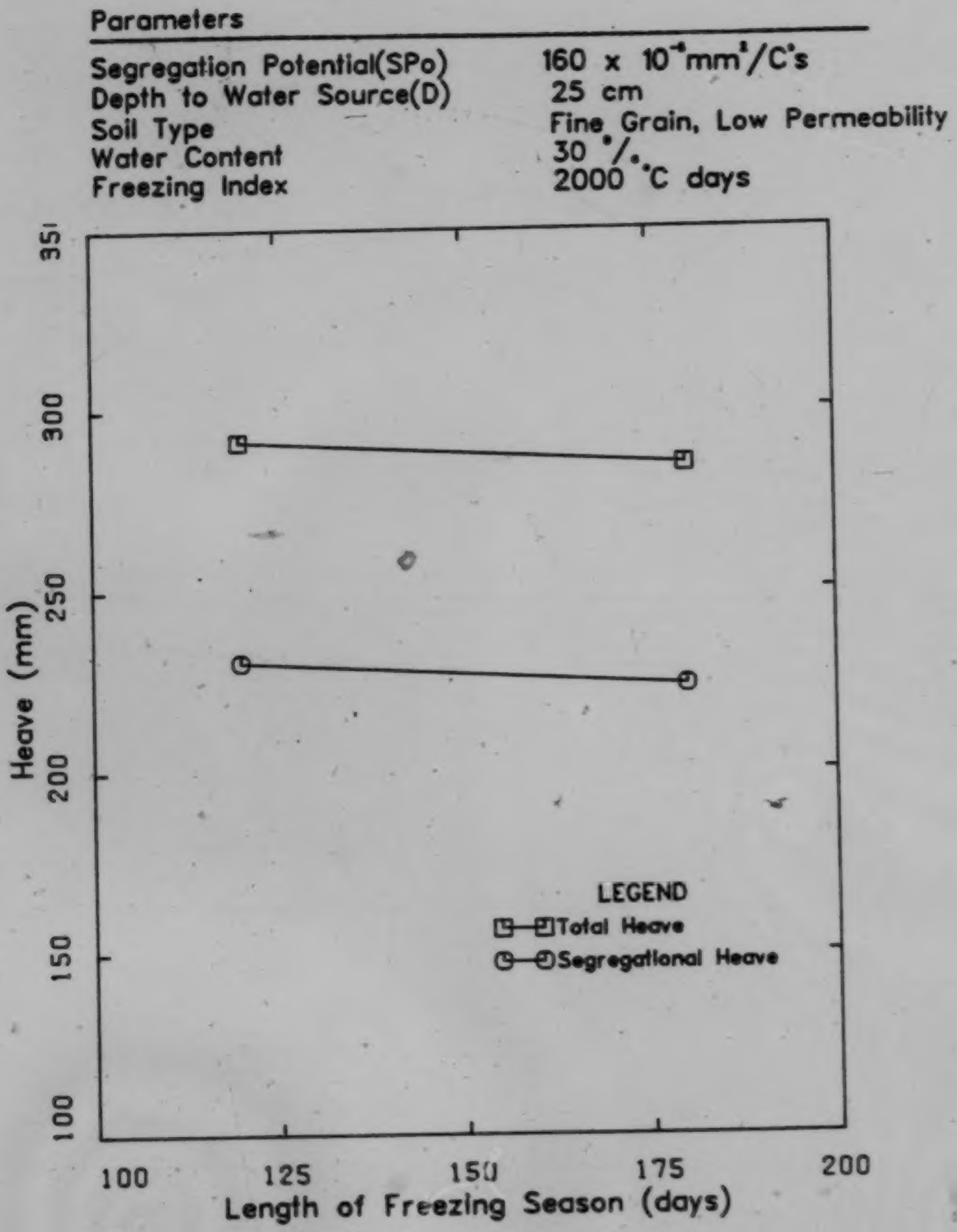


Figure 4.4 Influence of freezing season length on the magnitude of frost heave.

Parameters	
Segregation Potential(SPo)	320 x 10^{-5} mm^2/C°s
Depth to Water Source(D)	25 cm
Soil Type	Fine Grain, Low Permeability
Water Content	30 %
Freezing Index	1000 °C days

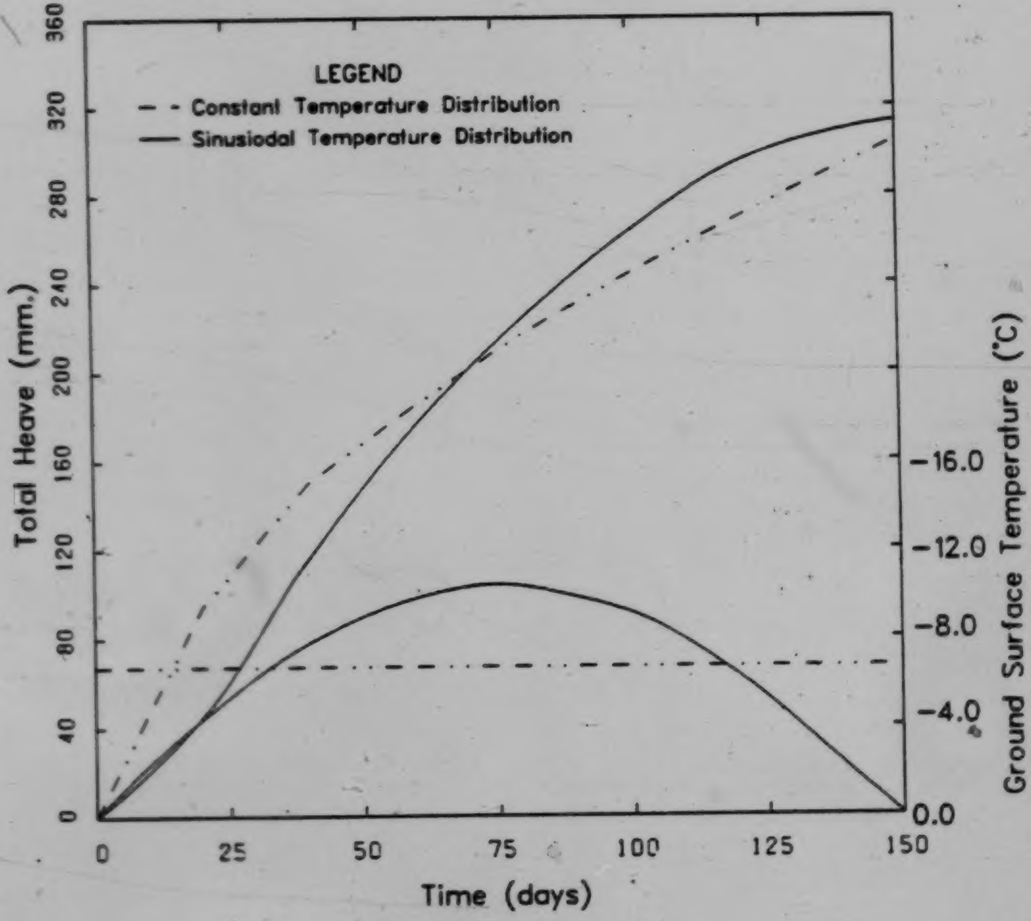


Figure 4.5 Influence of freezing temperature distribution on the magnitude of frost heave.

Parameters	
Segregation Potential(SPo)	160 x 10^{-5} mm^2/C°s
Depth to Water Source(D)	0 cm
Soil Type	Fine Grain
Water Content	30 %
Freezing Index	2000 °C days

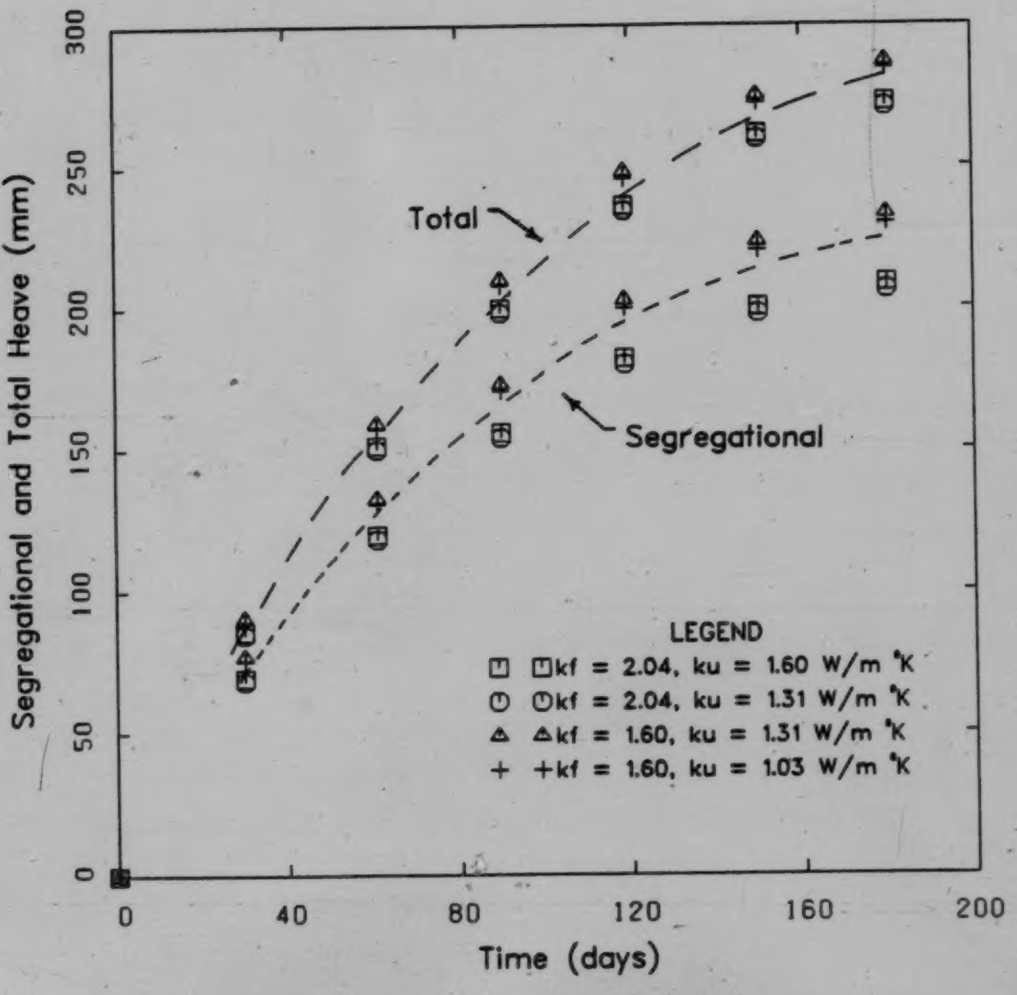


Figure 4.6 Sensitivity of the magnitude of heave to the thermal conductivity of the soil.

Parameters	
Segregation Potential(SPo)	160 x 10^{-5} mm^2/C°s
Depth to Water Source(D)	50 mm
Thickness of Saturated Soil(S)	50 mm
Freezing Index	1000 °C days

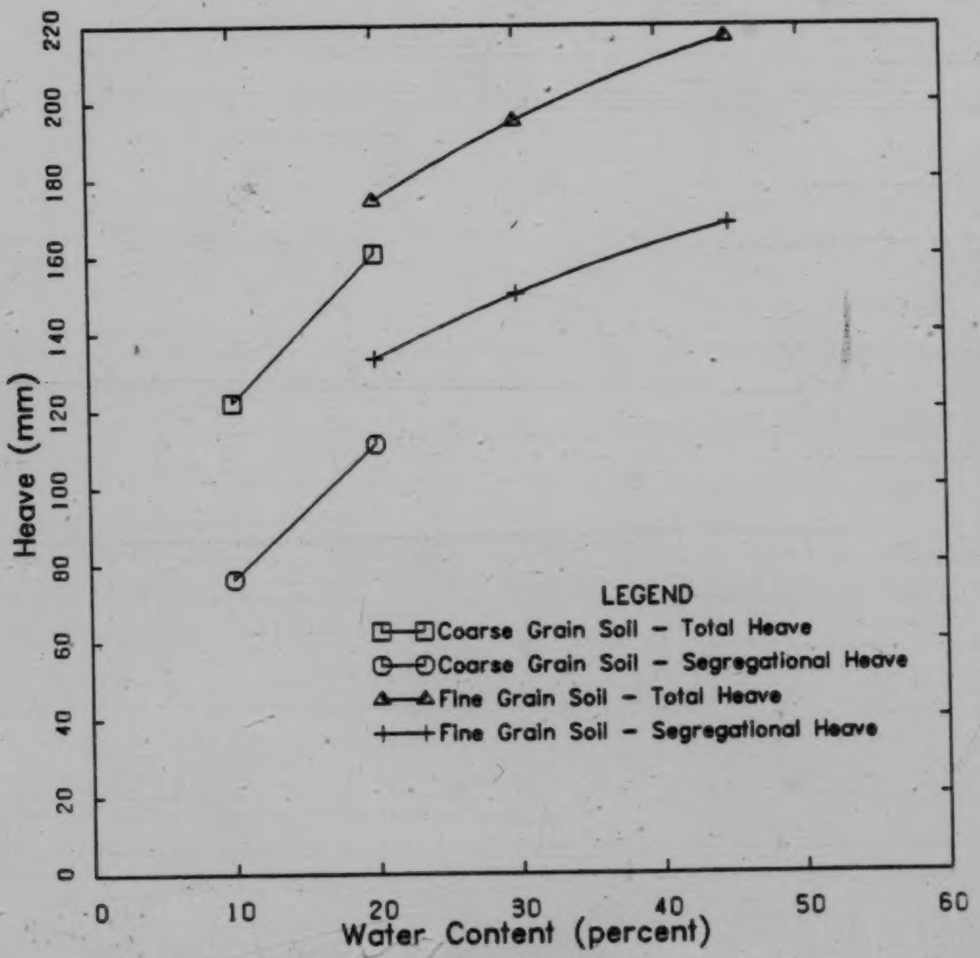


Figure 4.7 The influence of soil type on the magnitude of Heave.

Parameters	
Segregation Potential(SPo)	160 x 10^{-5} $mm^2/C^\circ s$
Depth to Water Source(D)	1000 mm
Thickness of Saturated Soil(S)	1000 mm
Water Content	30 °/。
Freezing Index	2000 °C days

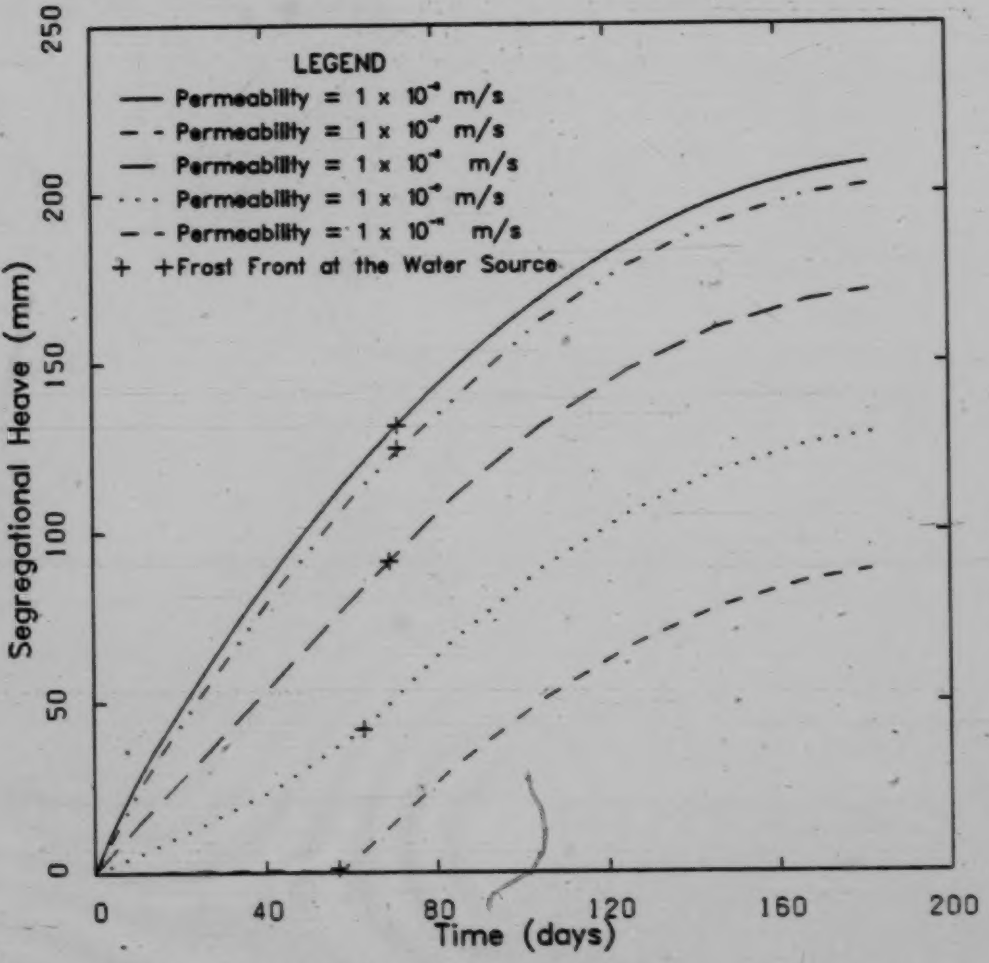


Figure 4.8 Influence of permeability on the magnitude of heave.

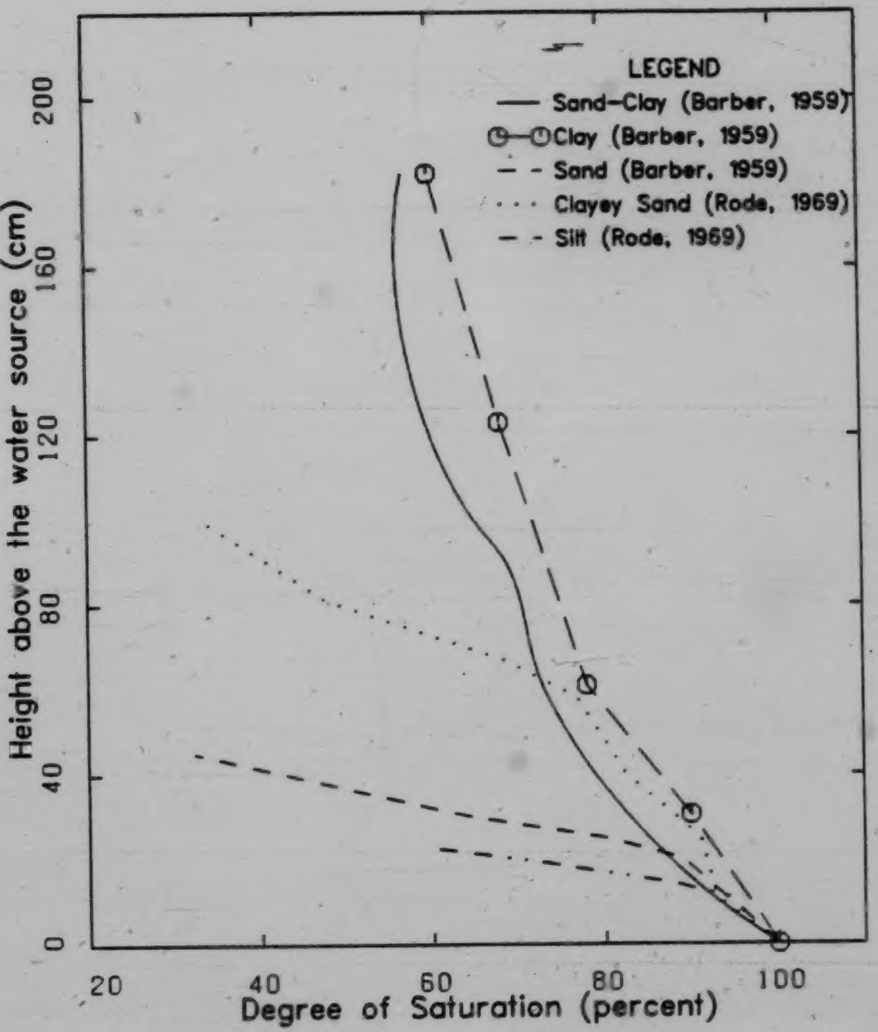


Figure 4.2 Degree of saturation profiles.

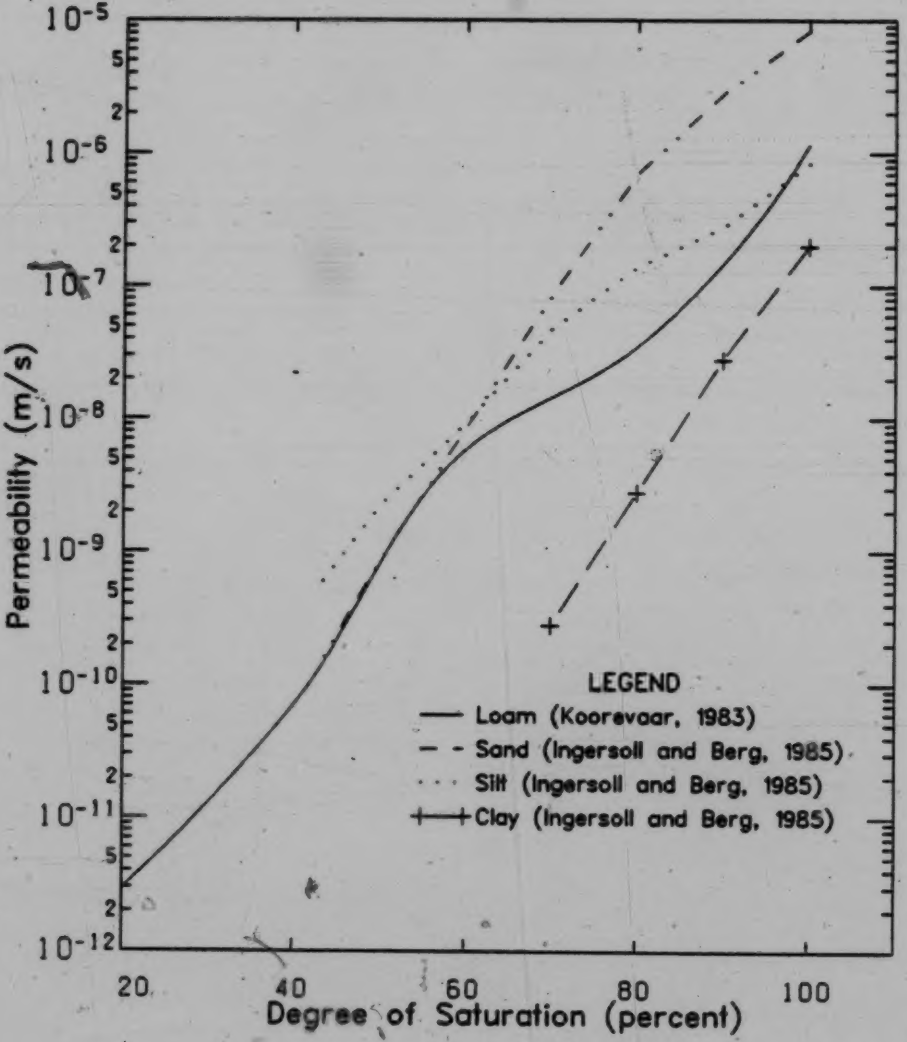


Figure 4.10 Permeability of a partially saturated soils

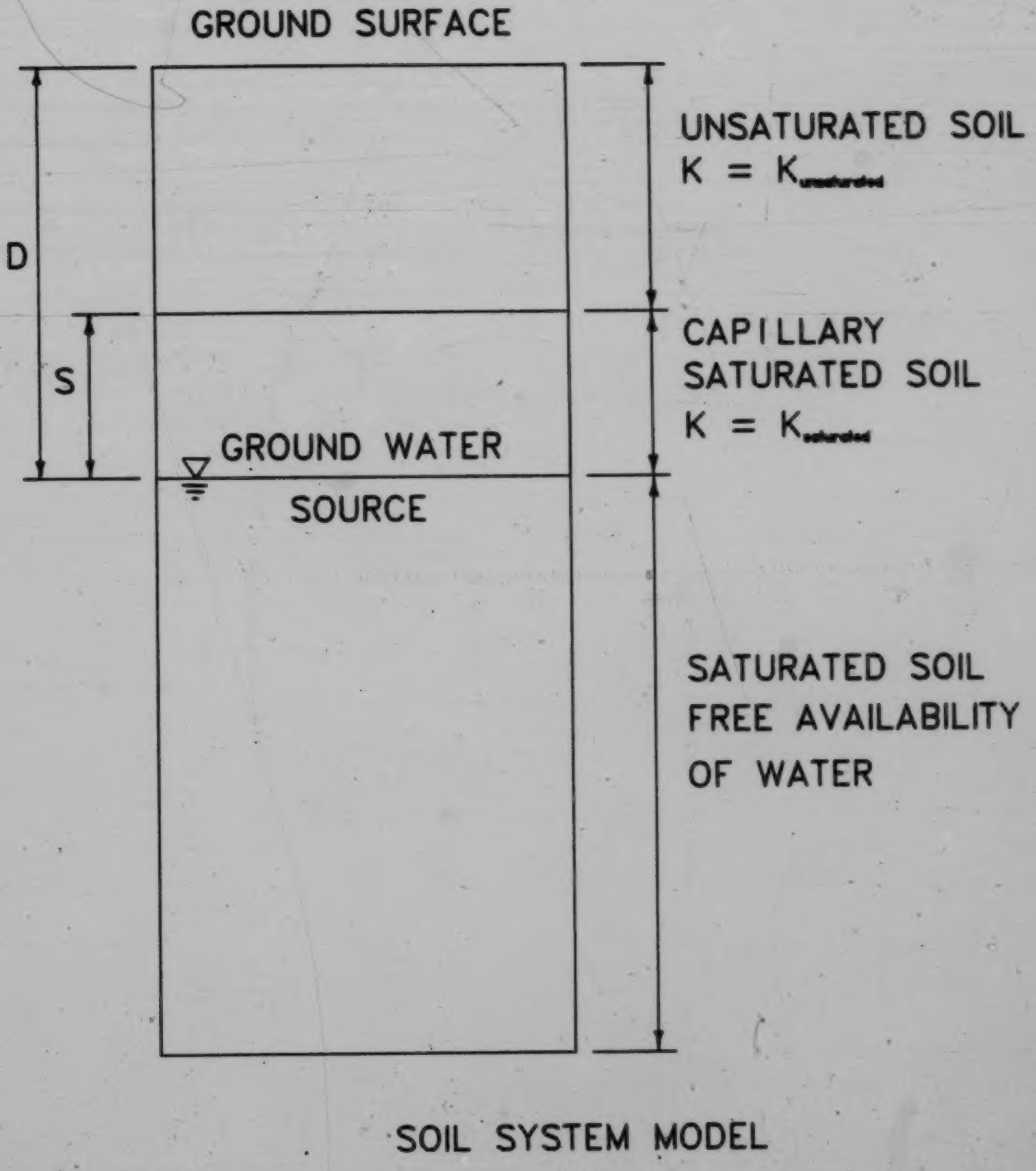

GROUND SURFACE
UNSATURATED SOIL
$K = K_{unsaturated}$
D
S
CAPILLARY
SATURATED SOIL
$K = K_{saturated}$
GROUND WATER
SOURCE
SATURATED SOIL
FREE AVAILABILITY
OF WATER
SOIL SYSTEM MODEL

Figure 4.[illegible] Soil system model.

Parameters	
Segregation Potential(SPo)	160 x 10^{-5}mm^2/C°s
Freezing index	2000 °C days

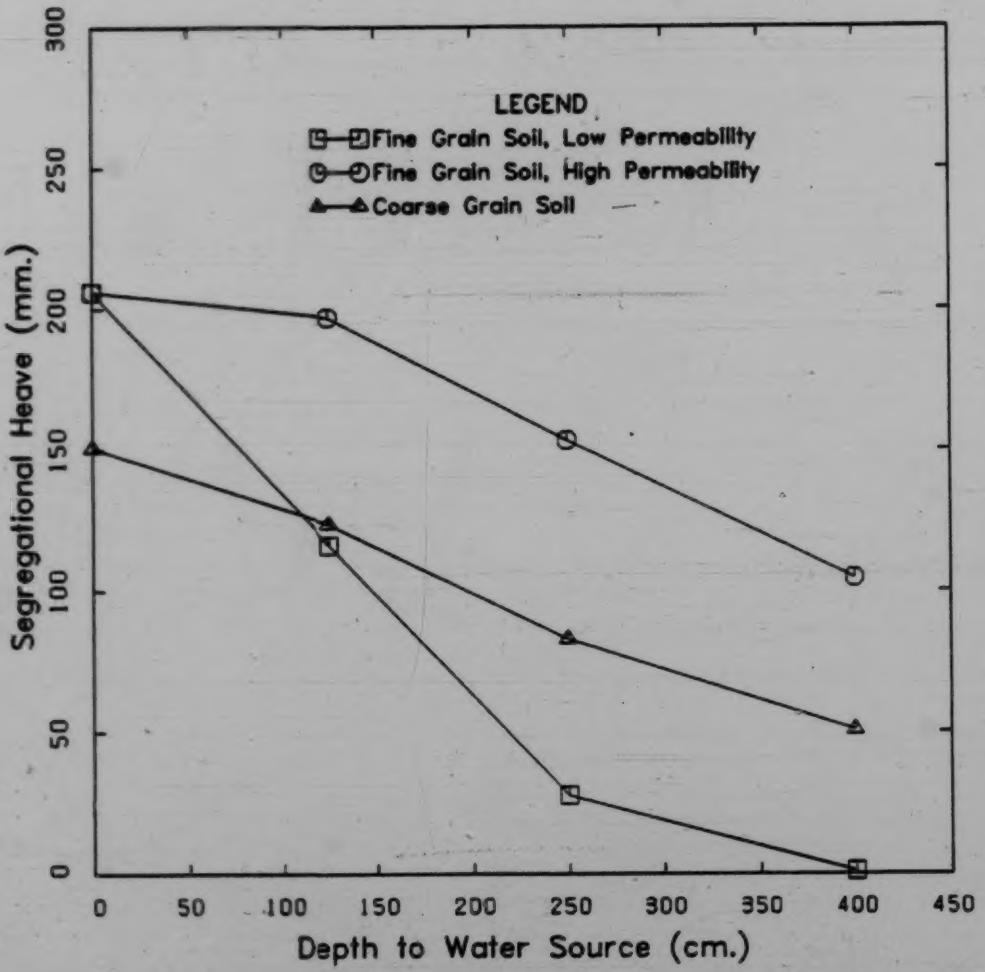


Figure 4.12 Influence of depth of water source on the magnitude of heave.

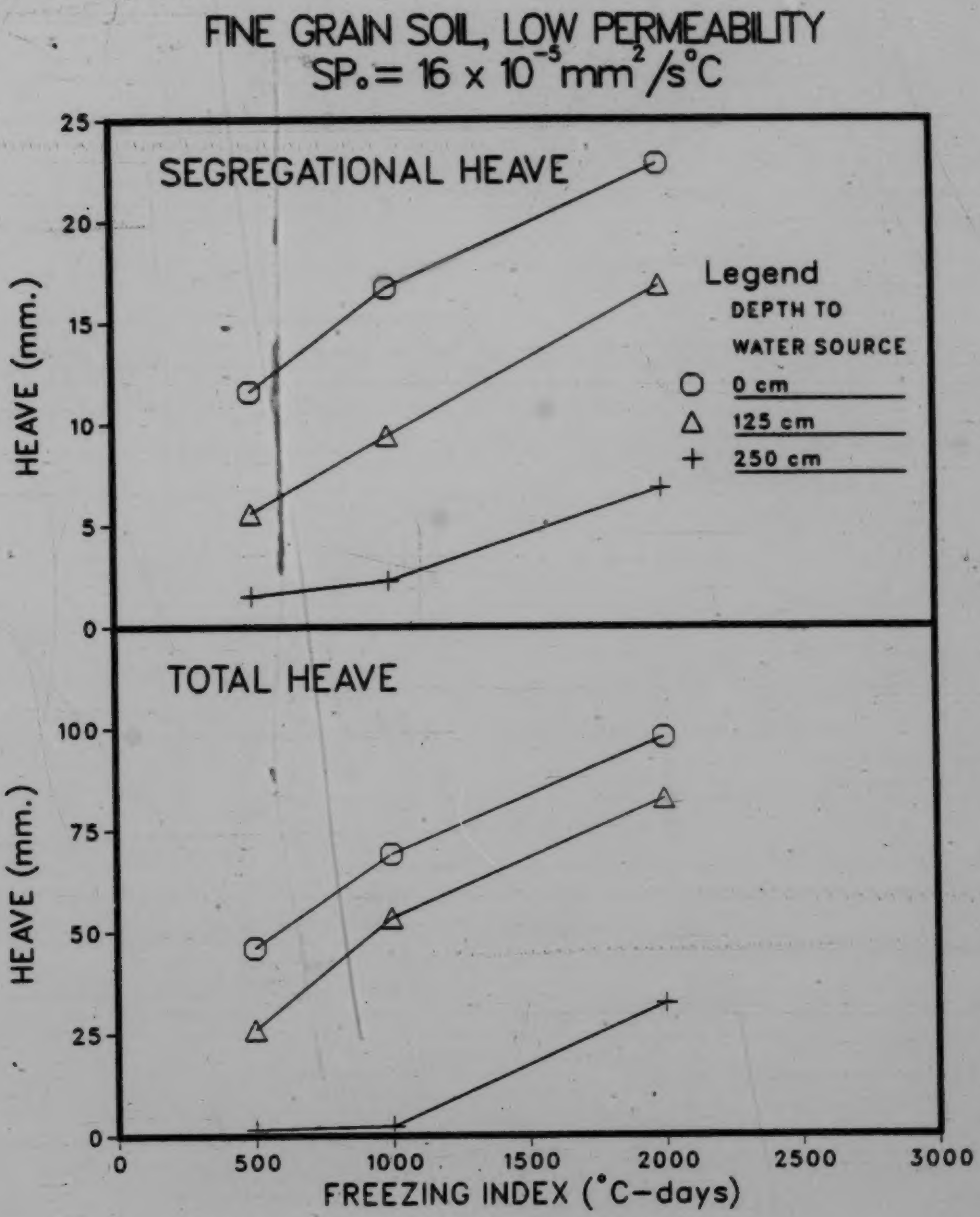


Figure 4.13 Heave of a low permeable fine grained soil, SP_0 = 16 x 10^{-5}mm^2/s°C

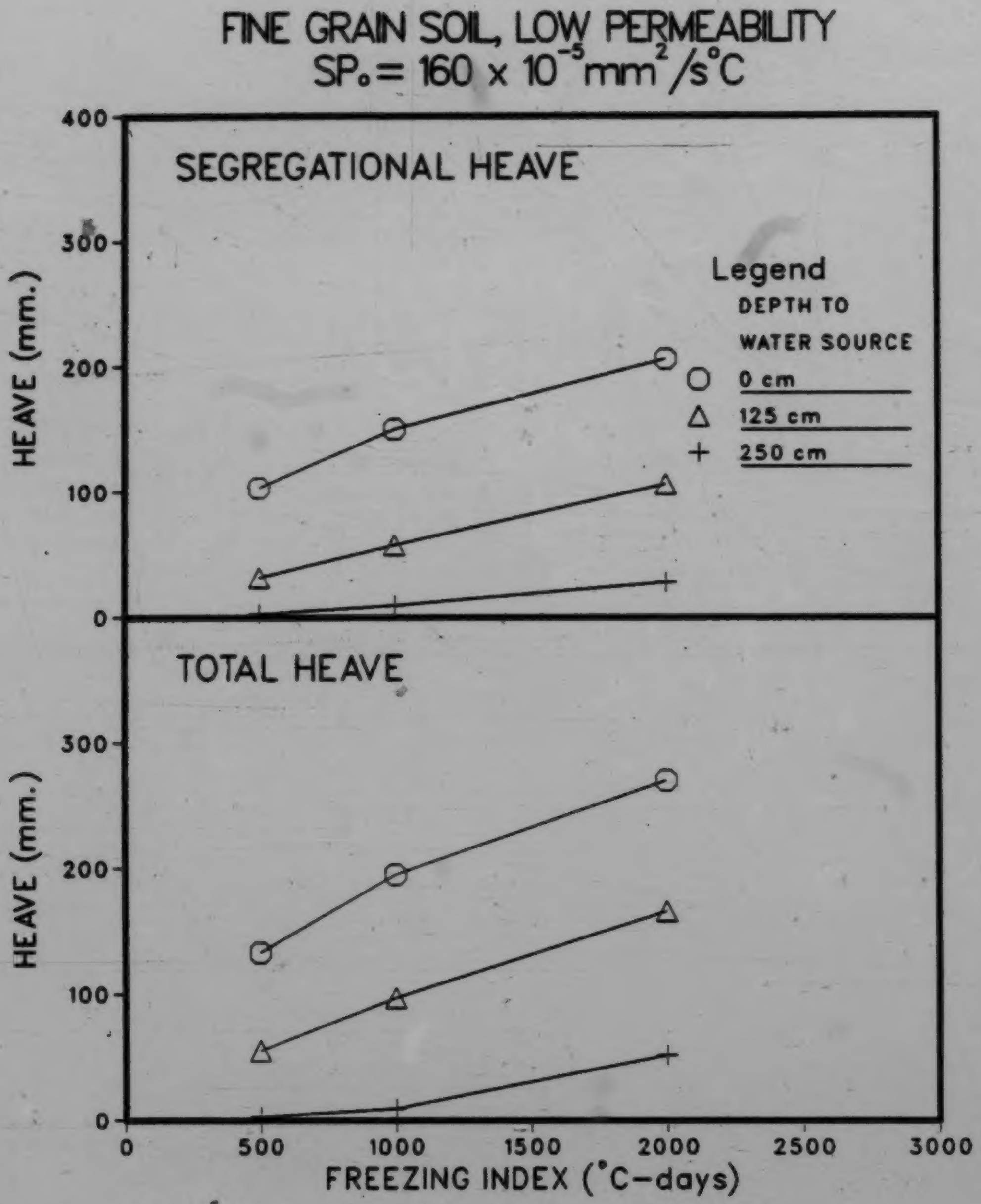


Figure 4.14 Heave of a low permeable fine grained soil, SP_0

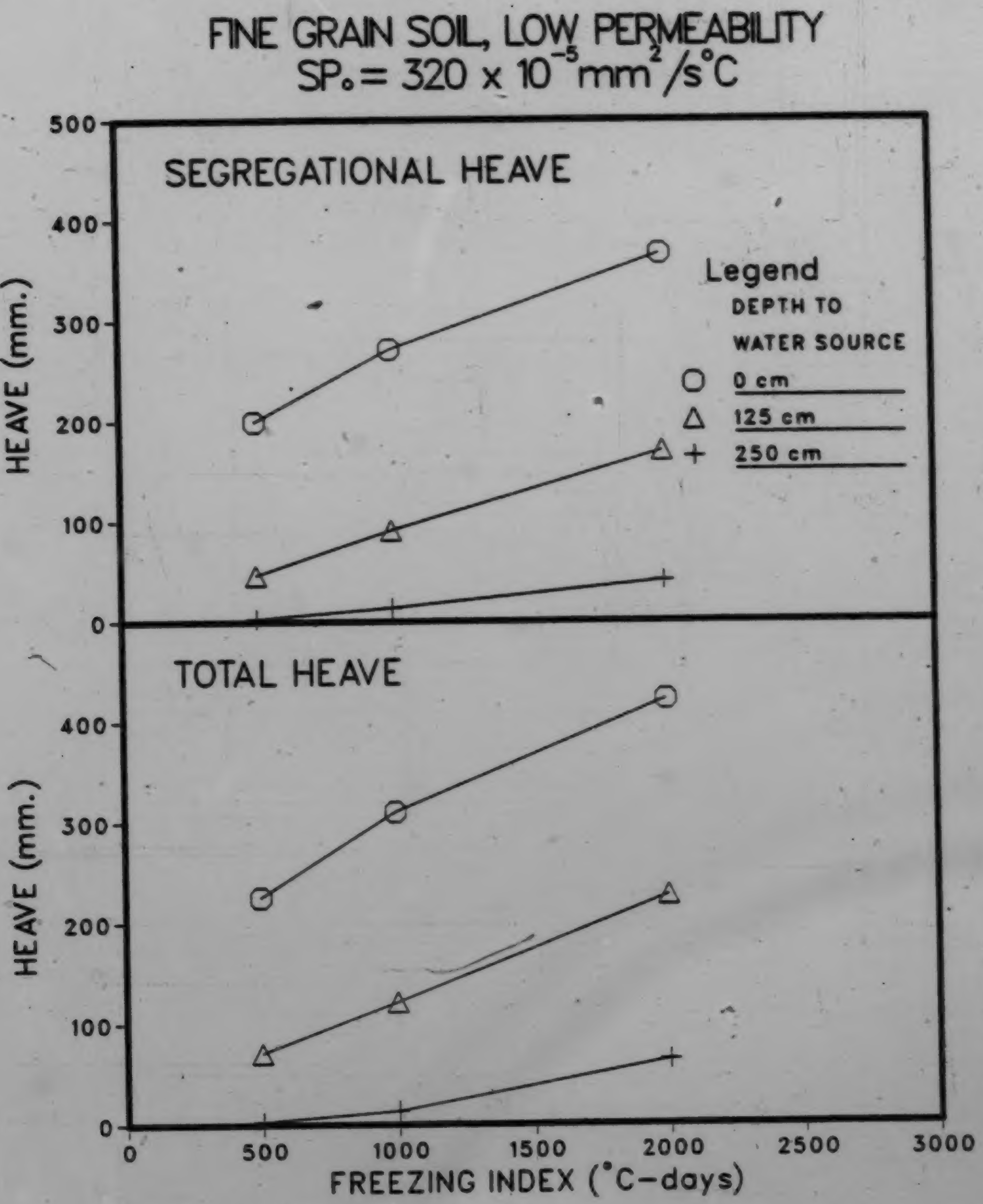


Figure 4.15 Heave of a low permeable fine grained soil, $SP_0 = 320 \times 10^{-5} mm^2/s°C$

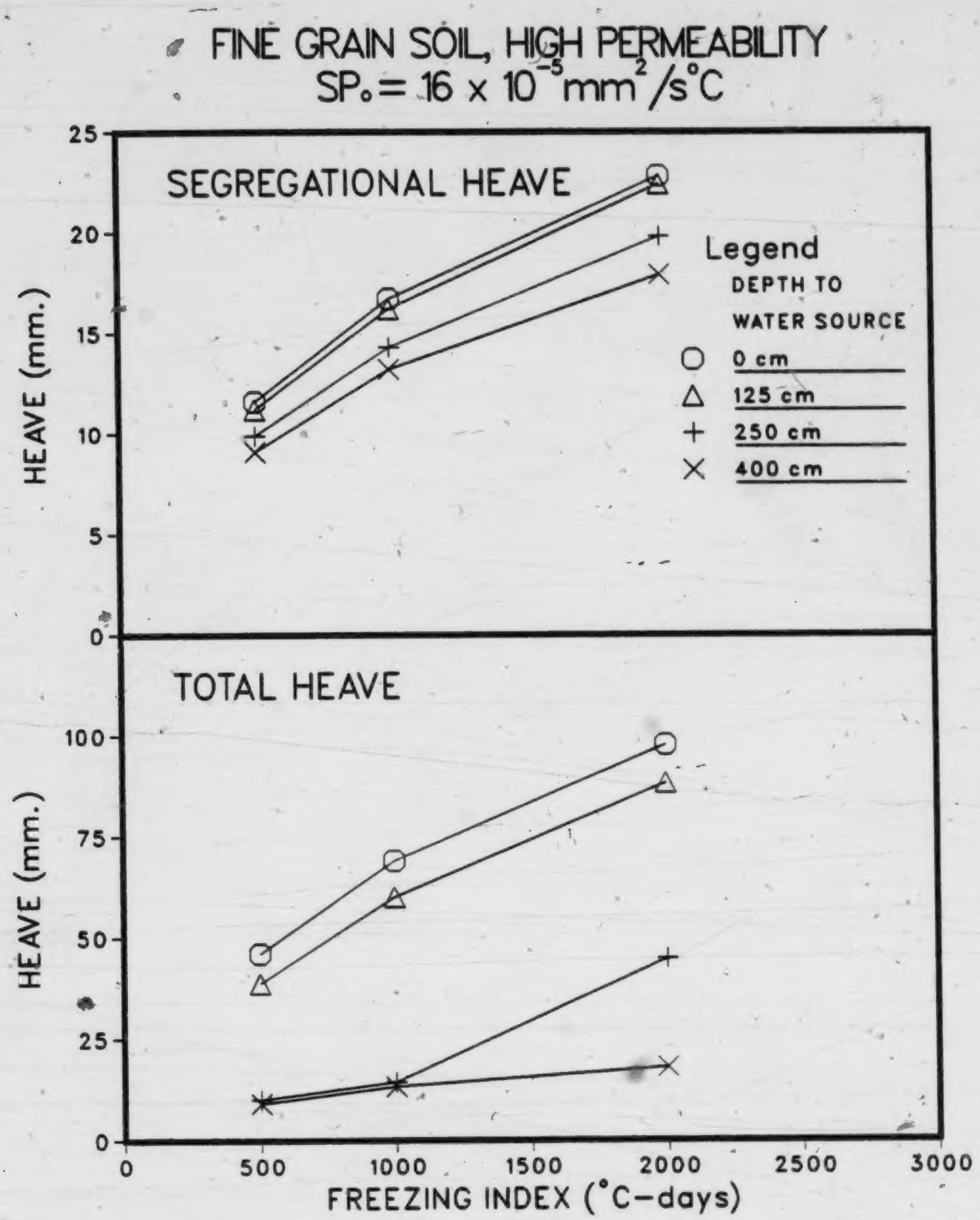


Figure 4.16 Heave of a high permeable fine grained soil, $SP_o = 16 \times 10^{-5} mm^2/s°C$

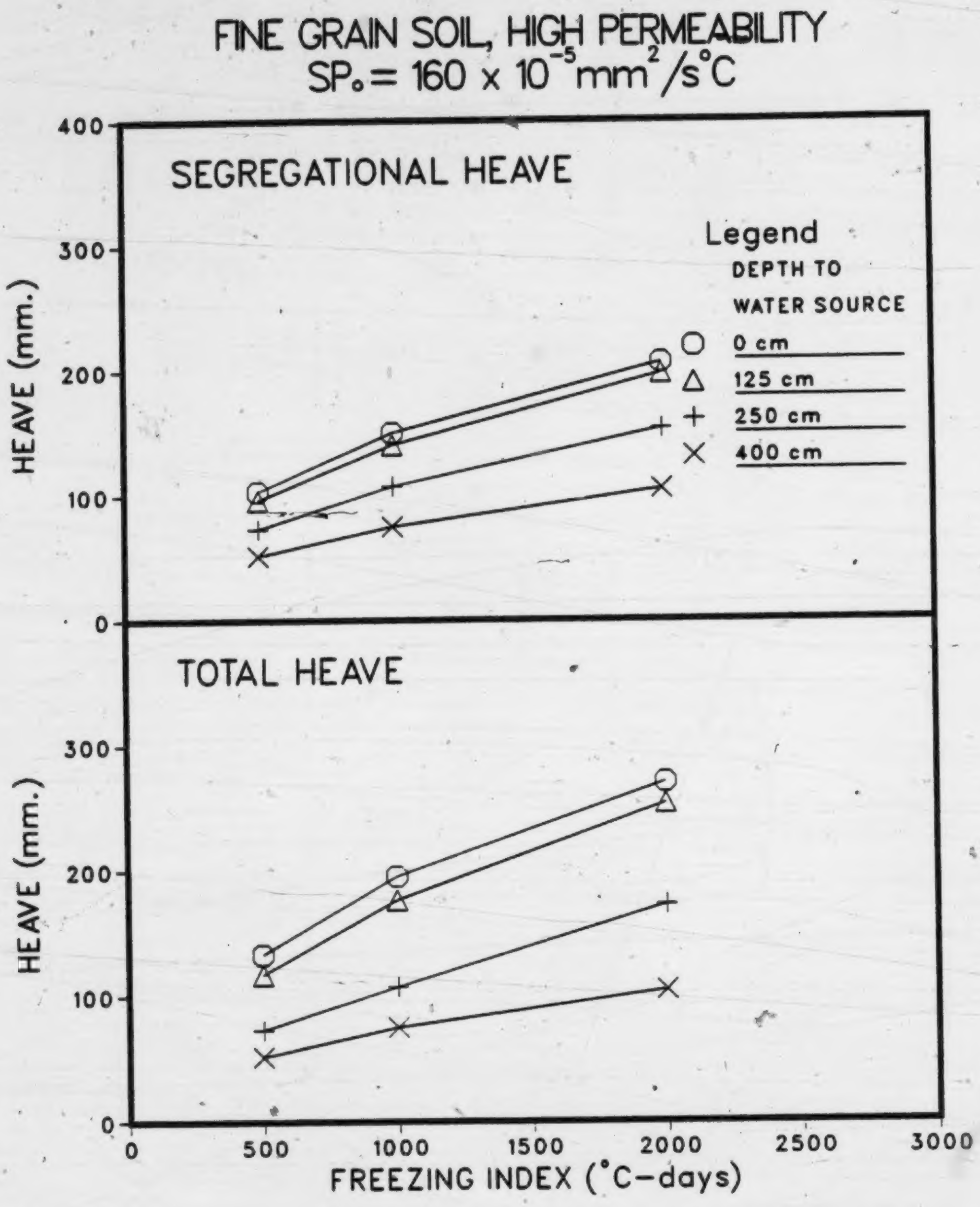


Figure 4.17 Heave of a high permeable fine grained soil, $SP_0 = 160 \times 10^{-5} mm^2/s°C$

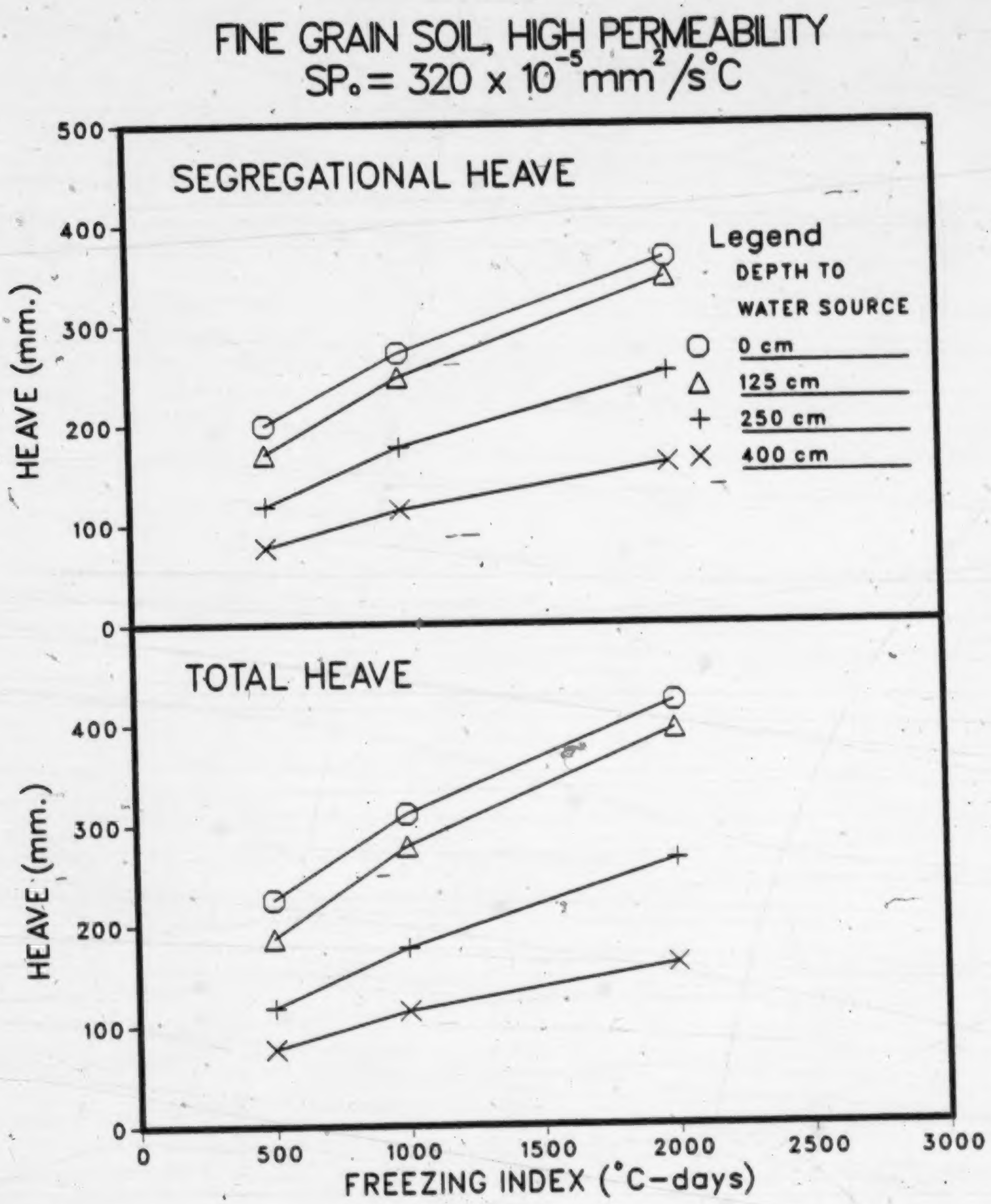


Figure 4.18 Heave of a high permeable fine grained soil, $SP_o = 320 \times 10^{-5} mm^2/s°C$

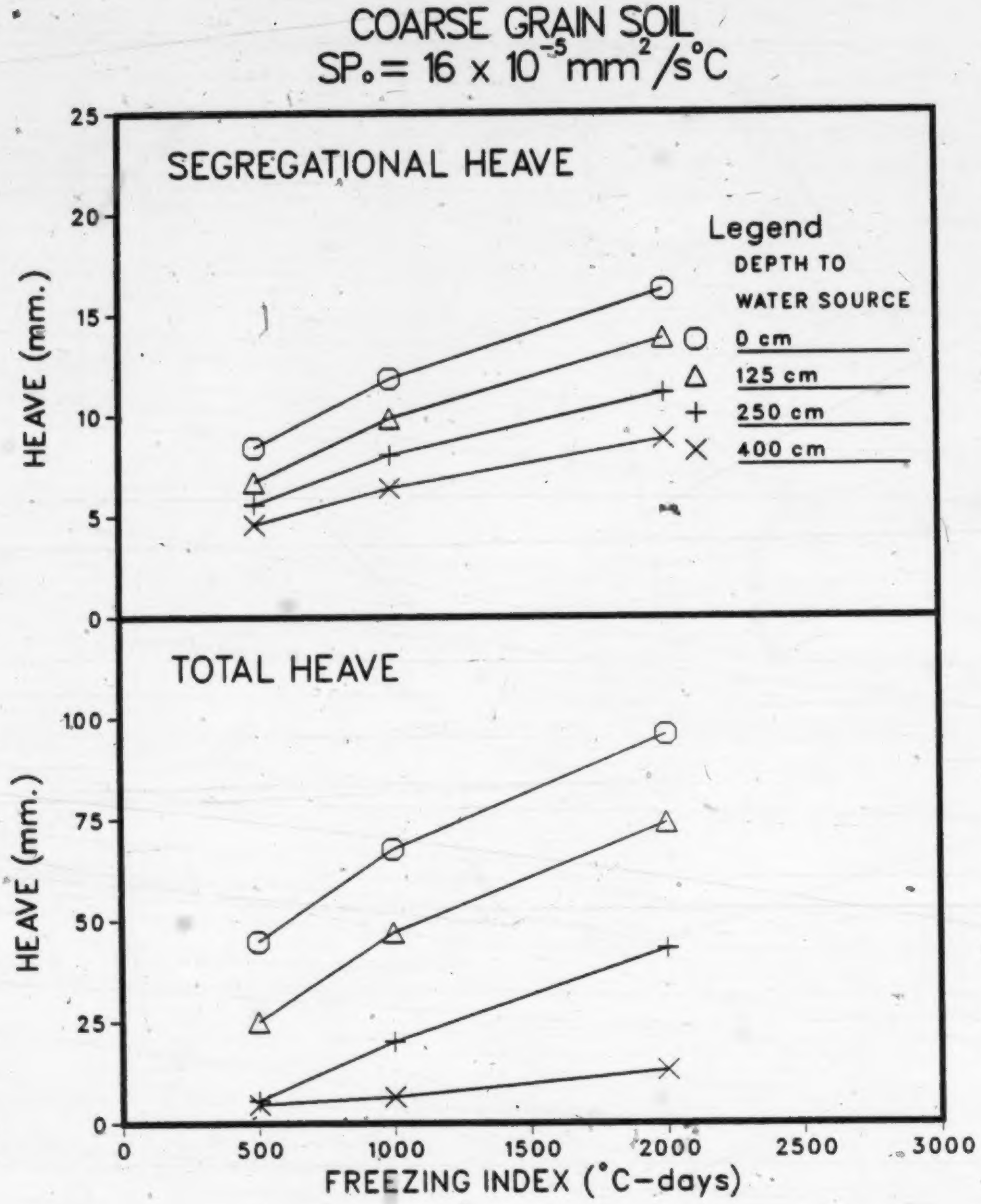


Figure 4.19 Heave of a coarse grained soil, $SP_0 = 16 \times 10^{-5} mm^2/s°C$

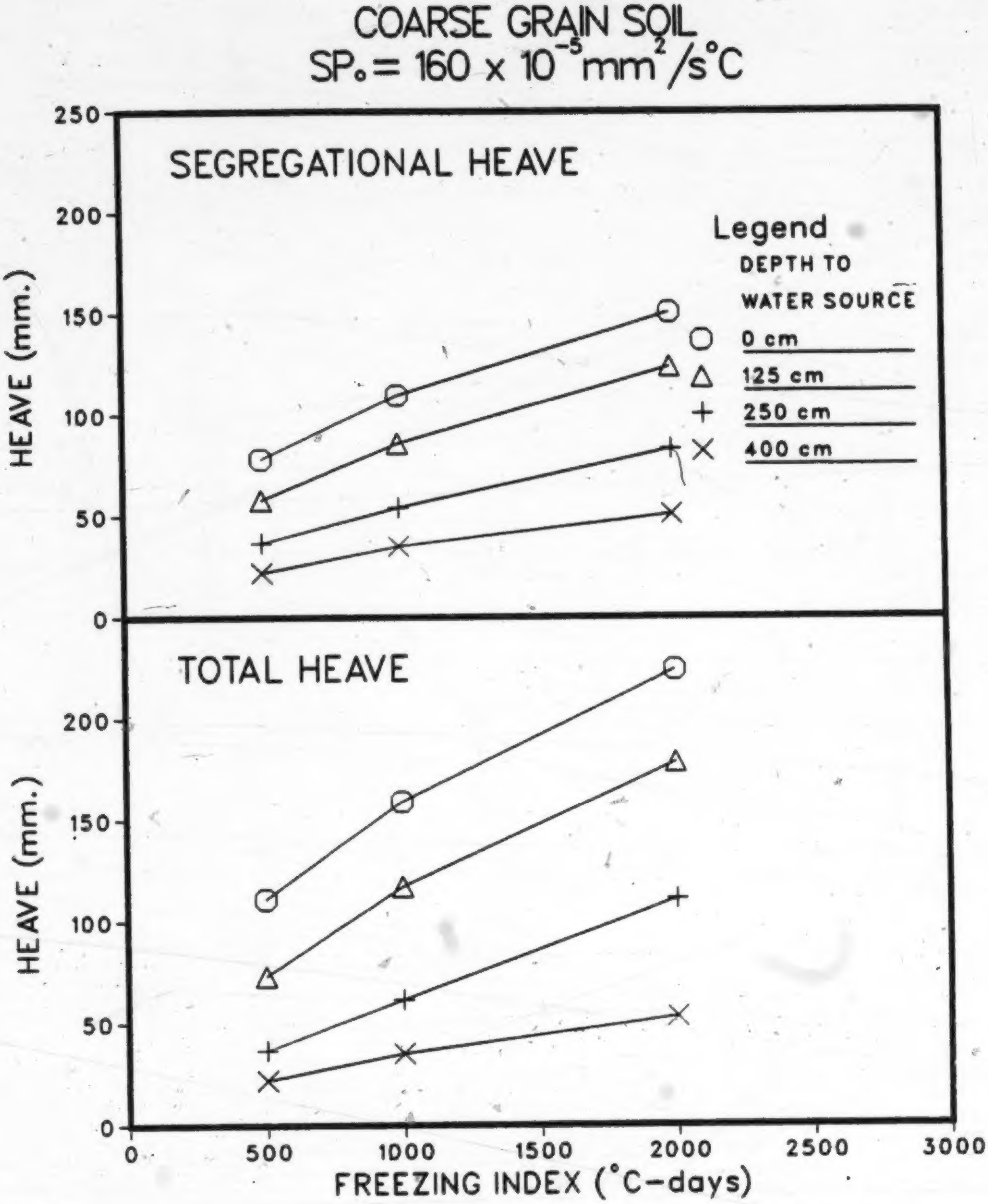


Figure 4.20 Heave of a coarse grained soil, SP_o = 160 x $10^{-5}mm^2/s°C$

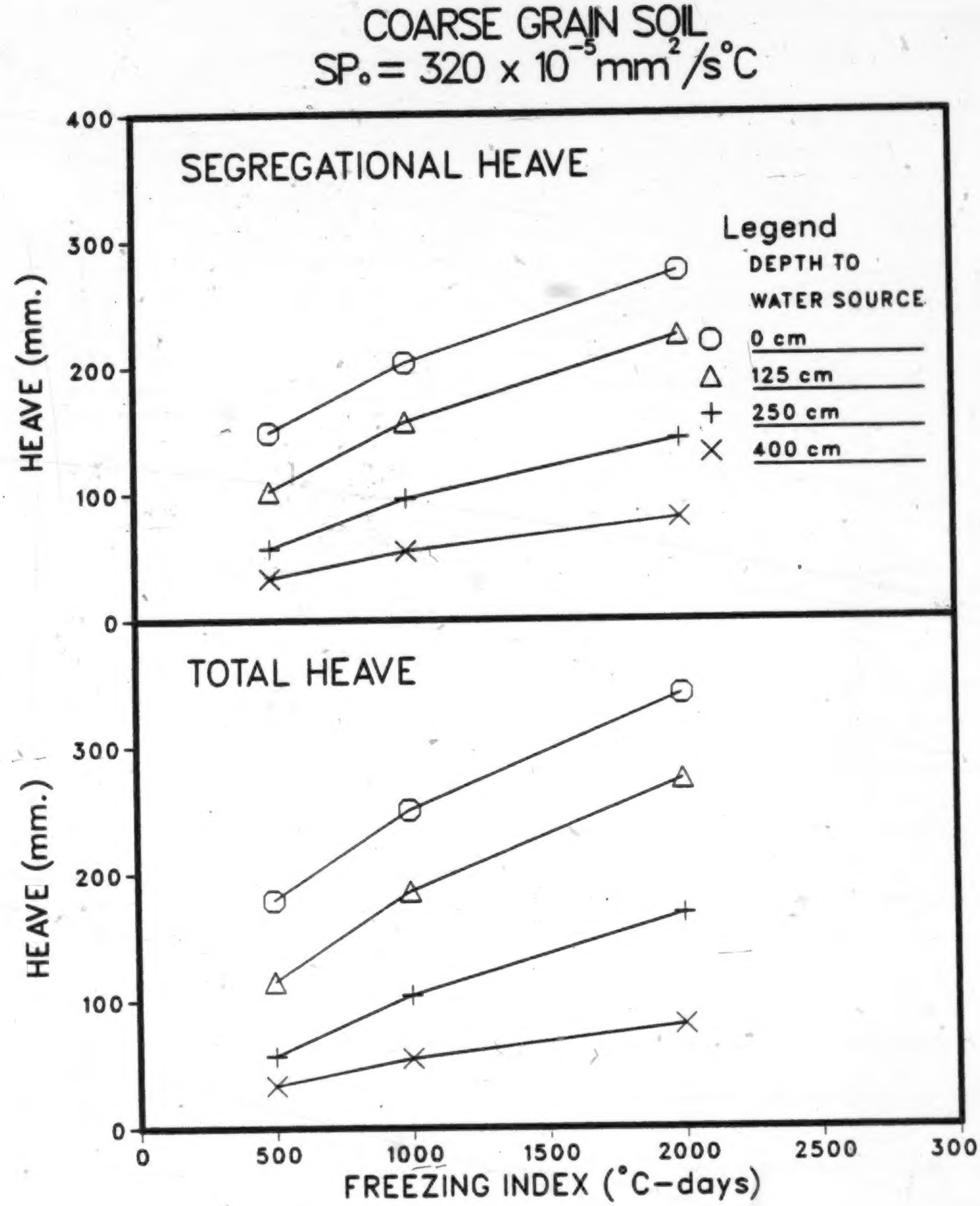


Figure 4.21 Heave of a coarse grained soil, $SP_o = 320 \times 10^{-5} mm^2/s°C$

Parameters	
Segregation Potential(SPo)	160×10^{-5} mm^2/C°s
Depth to Water Source(D)	0 cm
Soil Type	Fine Grain
Water Content	30 %

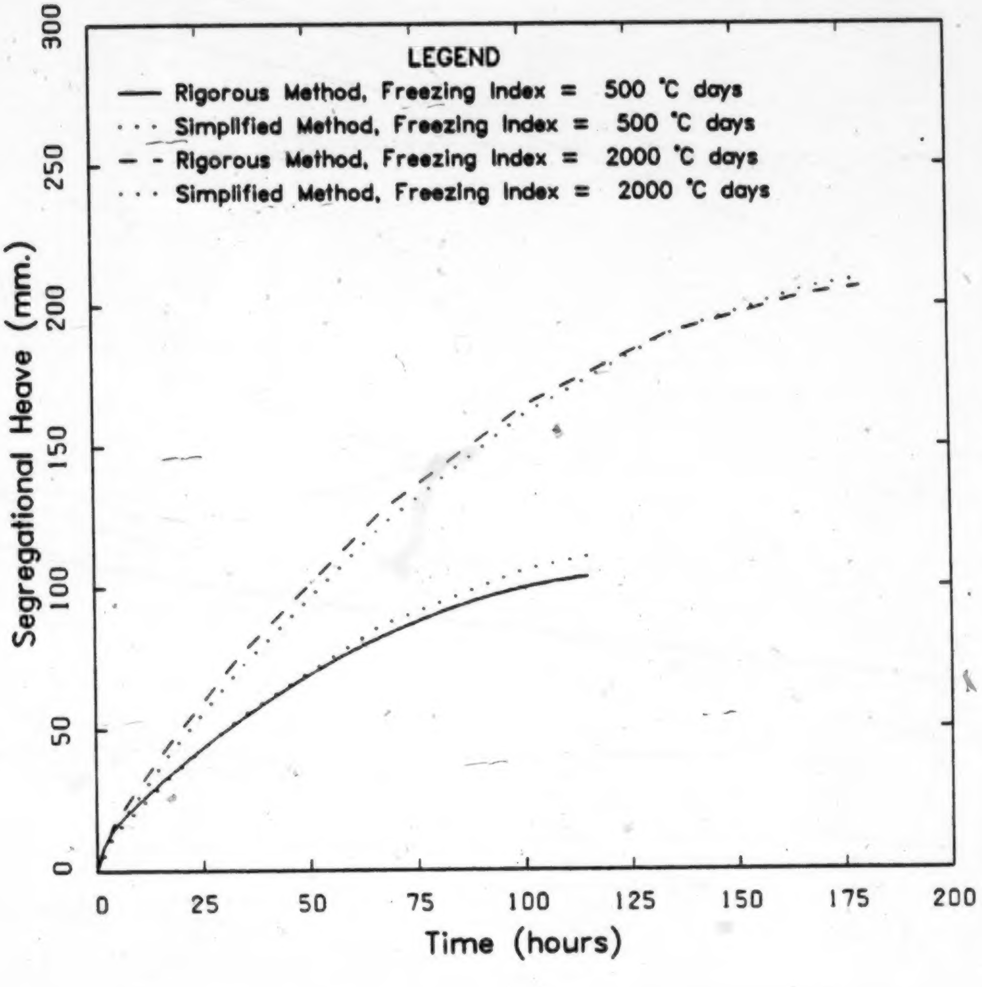


Figure 4.22 Comparison between simplified and rigorous methods of frost heave prediction.

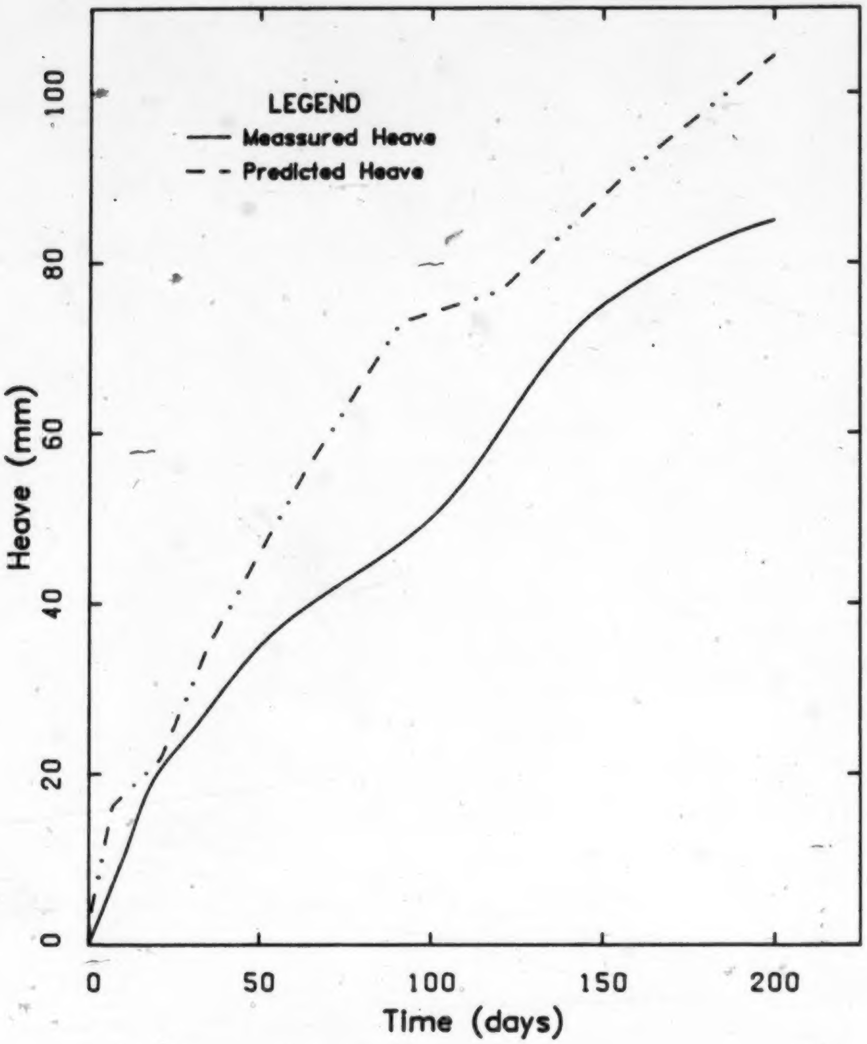


Figure 4.23 Measured and predicted heave of an insitu freezing test (Nixon, 1982).

5.0 CONTROL OF FROST HEAVE BY INSULATING LAYERS

5.1 Introduction

This chapter is concerned with heave under buildings and methods of reducing the magnitude of heave. It is proposed to reduce the heave by means of insulating layers under the foundations of the buildings. Insulating layers reduce the heat flow from a freezing soil, thereby reducing the temperature gradient within the frozen fringe. This results in a decreased magnitude of frost heave.

For structures sensitive to heave it would be desirable to eliminate all frost heave. This can be achieved by preventing frost penetration below the footings. Robinsky and Bespflug (1973) determined the amount of insulation required to prevent frost penetration below heated and unheated buildings. Generally, less than a 5 cm thick insulation layer is required to prevent frost penetration under the footings of heated buildings. An unheated building that experiences a freezing index of 2000 °C days requires a 20 cm thick insulation layer to prevent frost penetration under the building. The cost of a 20 cm thick layer insulation layer may not be justified for some projects. This chapter is concerned with reducing heave under buildings rather than eliminating it.

5.2 Two Dimensional Estimation of Frost Heave

Heat flows through and around insulation, and as a result the heat flow is no longer one dimensional. In the case of perimeter insulation around a building, the insulating layers are much longer than they are wide; therefore, the heat flow can be modelled using a two dimensional heat flow model.

The temperature distribution below the building is solved by a computer program developed by Ho (1969). The listing of this program and a sample input and output is found in the Appendix C. The program describes the heat flow using an implicit finite difference formulation. Newton's iterative method is used to solve the finite difference equations. The program can handle different material properties and water contents for each element. The thermal properties and the ice formation characteristics can be expressed as a function of the temperature of the element. The program can apply various air temperature distributions, and can apply a correction factor for the temperature at the air-ground interface to account for boundary layer influences.

An estimate of the magnitude of heave was obtained by dividing the area into one dimensional vertical columns. The heave is calculated in each column using the simplified one dimensional method of frost heave prediction described in chapter 4. The program used to calculate the magnitude of heave from the results of the two dimensional heat flow model is presented in Appendix C.

5.3 Two Dimensional Finite Difference Grid and Boundary Conditions

The grid used for the finite difference analysis is shown in Figure 5.1. The shape of the grid was set up in order that it could be used for various insulation configurations. The segments were smaller in the region where the frost heave was to be calculated. This provides a more accurate determination of the temperature gradient in that region. A coarse grid was used elsewhere. Ho (1969) compared the results of the finite difference program to a measured temperature distribution of a highway embankment. He found that the temperature distribution obtained from both a coarse grid and a fine grid approximated the temperature distribution in the field. A time step of 2 hours was used in the analysis so that it was accurate, stable and efficient.

It was assumed that the heat flow is symmetrical about the center of the building; therefore, the left boundary was set as a symmetrical boundary. The right boundary is set as an infinite boundary. The distance from the building to the right boundary and the depth of the lower boundary are set so that the boundaries have little influence on the heat flow.

The lower boundary was kept constant at 4 °C throughout the analysis. A sinusoidal temperature distribution was used for the cold side. The number of freezing days in the season was the same as that used in the one dimensional model. The "n-factor" between the ground freezing index and the air freezing index was taken as 0.9 inside the building and 1.0 outside the building.

5.4 Comparison of the Two Dimensional Model to the One Dimensional Model

The magnitude of frost heave in the two dimensional model was calculated in the same manner as the simplified one dimensional model. Appendix C. contains the program used to calculate the frost heave from the temperature distribution obtained from the two dimensional heat flow program. The major difference between the two analyses was that the grid of the two dimensional analysis has to be very coarse in comparison to the one dimensional model. The coarse grid is required to keep computational time within reasonable limits. The coarser grid makes the determination of the temperature gradient in the frozen fringe less accurate.

The two dimensional model does not consider the latent heat of the intake water or the increase in frozen length caused by the heave. Figure 5.2 shows the temperature gradient in the frozen soil obtained from the rigorous method for various segregation potentials. It is apparent that the intake water does not have a large influence on the temperature gradient for engineering purposes.

A comparison was conducted between the rigorous method described in chapter 4 and the simplified method of frost heave estimation used in the two dimensional case. The boundary conditions applied to the two dimensional analysis cause the heat flow to be one dimensional. The properties of a fine grained soil with a moisture content of 30% were used for both analyses. The temperature gradient in the frozen fringe determined from the two analyses is illustrated in Figure 5.2. The agreement of the temperature gradients from the two methods justify ignoring the intake water and the use of a coarse grid.

5.5 Parameters for the Two Dimensional Analysis

The influence of soil type and water content on the magnitude of heave was explored in chapter 4. It was found that for soils with similar SP data the soil type did not have a great influence on the magnitude of heave. The soil properties of a fine grained soil with a 30% moisture content were used in all analyses in Chapter 5.

It was assumed that the water table is at the surface in all analyses. As discussed in Chapter 4 this results in an upper bound magnitude of frost heave.

The thermal properties of the top layer of elements outside the building are set to the thermal properties of snow. Inside the building the thermal properties of the top layer are set to the thermal properties of gravel. Figure 5.6 illustrates the various insulation configurations analyzed. The thermal properties of the materials used in the analysis are shown in table 5.1. These properties were obtained from Anderson and Andersland (1978) and Johnston (1981).

Snow cover reduces the magnitude of heave by providing insulation protection. Figure 5.3 illustrates the influence of snow cover outside the building on the magnitude of heave under the center of the footing. Potter (1965) has compiled snow cover data for specific localities in Canada. The average snow cover of some selected Canadian cities is presented in Appendix A. For this analysis the average snow cover over the freezing season was taken as 10 cm. It should be noted that 10 cm snow cover reduces the frost heave by approximately 20% from the case of no snow cover. Therefore if the results of this analysis were to be used for design in a situation where less than 10 cm of snow cover is anticipated an allowance should be made for an increase in the magnitude of heave.

The two dimensional model allows the initial ground temperature distribution to be input. Ground temperature profiles can be obtained for specific localities in Canada from Phillips and Aston (1979). By examining these profiles it was concluded that the typical ground temperature profile at the beginning of the freezing season is that shown in Figure 5.4. Due to lack of data on ground temperture distributions under unheated structures the initial ground temperature distribution under the building was assumed to equal the ground temperature outside of the building.

Figure 5.5 shows the comparison of the magnitude heave between a constant soil temperature of 4 °C and the profile shown in Figure 5.4. The heave experienced in the case where a constant temperature distribution is used is slightly less than in the case where a typical ground temperature profile is used. For this analysis the temperature profile of Figure 5.4 is used since it is thought to more accurately represent the field condition.

5.6 Results of the Two Dimensional Analysis

The insulation configurations shown in Figure 5.6 have been analyzed for various segregation potentials, freezing indices and amounts of insulation.

Figure 5.7 shows the distribution of heave under the unheated building. The heave under the footing is less than the heave on either side of it even when there is no insulation. This is caused by the depth of the footing. Heave does not begin until the frost penetrates below the base of the footing. The base of the footing is 15 cm below the ground surface. Heave on either side of the footing begins as soon as the ground surface is frozen. The heave outside of the building is less than that inside of the building due to the snow cover outside of the building.

There is a considerable amount of differential heave between the insulated section and the uninsulated section. This is only acceptable if the area on either side of the insulated section can withstand this movement. If concrete floors or concrete aprons are used, insulation must be placed under them as well as the footing to avoid cracking caused by differential heave.

Figures 5.9 through 5.16 illustrate the heave for varying freezing indices, segregation potentials and insulation configurations. The magnitude of heave shown in the figures represents the heave under the center of the footing. Figures 5.9 through 5.12 have the base of the footing 15 cm below the footing. Figures 5.13 through 5.16 have the base of the footing 70 cm below the ground surface. The total heave is the combined segregational and insitu heave. The insitu heave is a function of the frost penetration and saturated moisture content. Generally the insitu heave will be constant over the site, as long as there is not a large variation in the moisture content over the site. The segregational heave is a function of the SP of the soil, temperature gradient and availibility of water. Experience has shown that segregational heave can result in differential movements over the site.

Figure 5.8 examines the effectiveness of the various insulation configurations by comparing the magnitude of frost heave under the center of the footing to the amount of insulation. Only a small amount of insulation (180 cm wide x 5 cm thick) is needed to reduce the magnitude of heave substantially from the case of no insulation. This amount of insulation will reduce the insitu heave and frost penetration by 25%, and the temperature gradient and the segregation heave by 65%. If the thickness of insulation is doubled (180 cm wide x 10 cm thick) the insitu heave is reduced by 35%, and the segregational heave is reduced by 77% compared to case of no insulation. From this analysis it is apparent that an increase in the quantity of insulation is not proportional to the reduction in the magnitude of frost heave.

Increasing the width of insulation from 180 cm wide to to 250 cm wide results only in a modest decrease in the magnitude of heave. In the case of insulation below the entire building only a modest decrease in the amount of heave is observed when width of insulation extending beyond the edge of the building is increased from 100 cm to 150 cm.

In the case of a deep footing the effects of frost heave can be eliminated if the tangential adfreeze bonds are reduced. Johnston (1981) discusses methods of reducing the adfreeze bonds. If the tangential forces are eliminated a combination of a deeper footing and insulation can be used to reduce the magnitude of frost heave. Figures 5.13 to Figures 5.16 show the magnitude of heave for a footing 70 cm. below the surface. In this case the heave caused by tangential forces was considered to be negligible. The heave is approximately 60% of the heave experienced by the footing at the surface.

The insulation requirements for a particular situation depends on the allowable deformations of the structure. The

Canadian Foundation Manual (1978) provides guidelines for the allowable deformation of structures. An example is presented in Appendix D. illustrating the determination of insulation requirements for a particular situation.

Table 5.1 Material properties used in the two dimensional analysis.

Material	Thermal Cond. W/m °K	Heat Capacity MJ/m³ °K	Water Content %
Soil-unfrozen	1.32	2.96	30.0
-frozen	2.01	2.02	-
Concrete	1.70	2.18	-
Gravel	2.26	1.99	1.0
Snow	0.26	0.40	-
Insulation	0.042	0.058	-

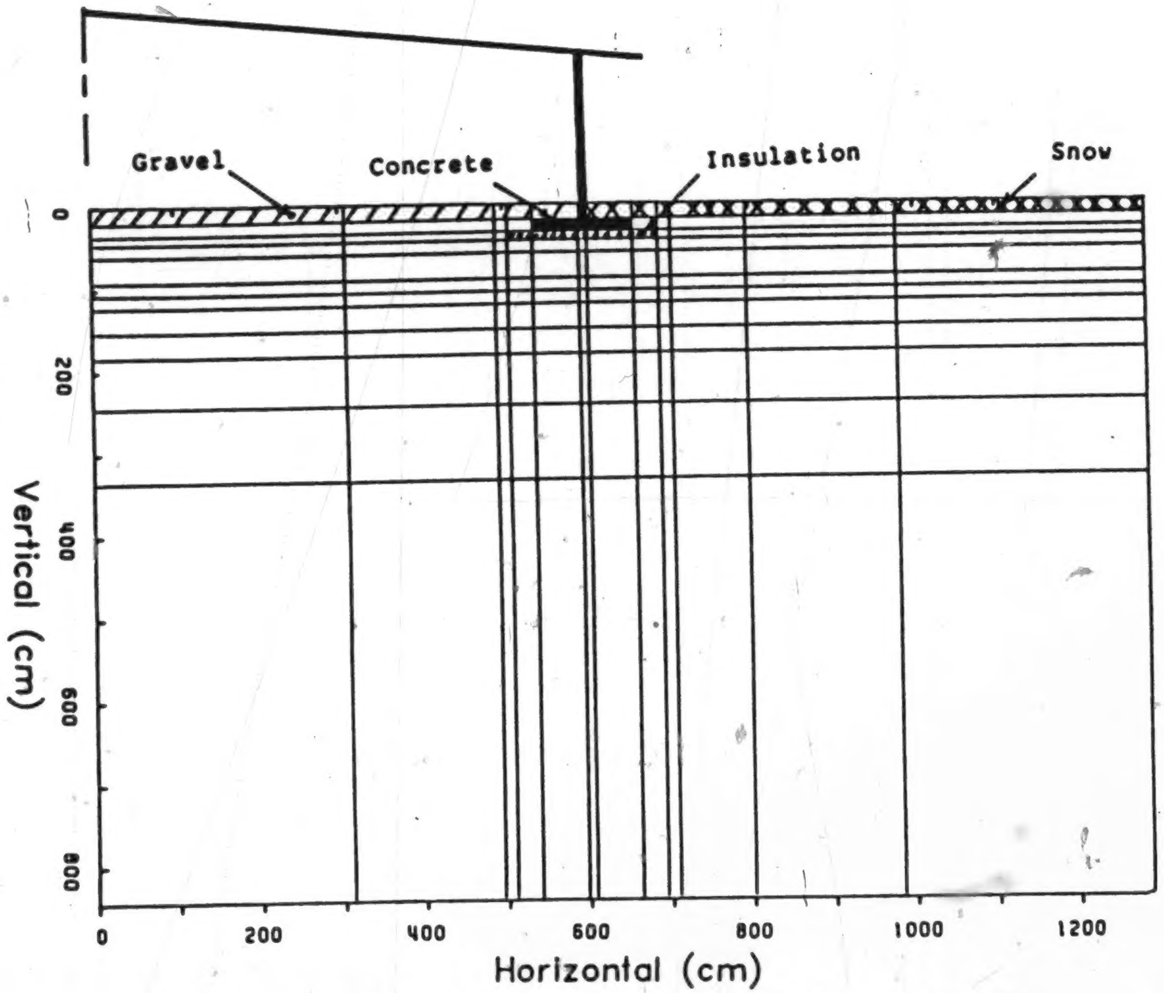

Gravel
Concrete
Insulation
Snow
0
200
400
600
800
Vertical (cm)
0
200
400
600
800
1000
1200
Horizontal (cm)

Figure 5.1 Two dimensional finite difference grid.

Parameters

Depth to Water Source(D)	0 cm
Soil Type	Fine Grain
Water Content	30 %
Freezing Index	2000 °C days

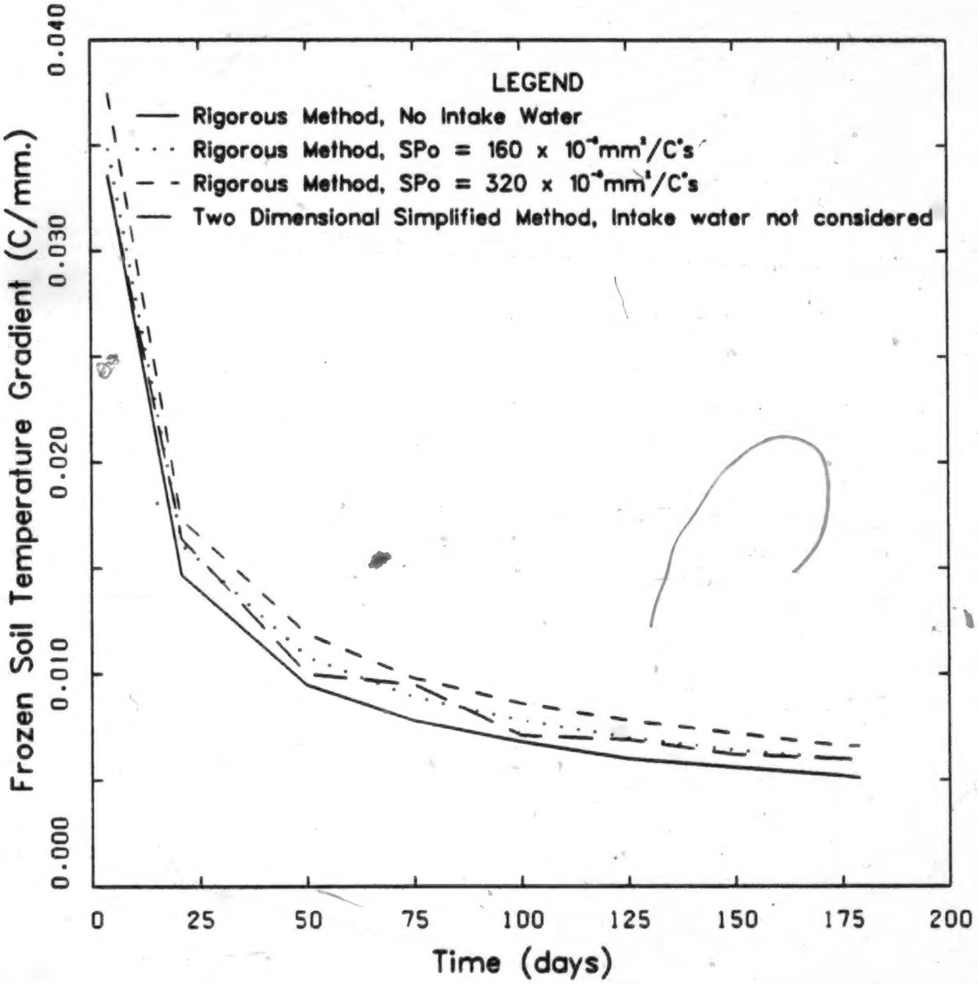
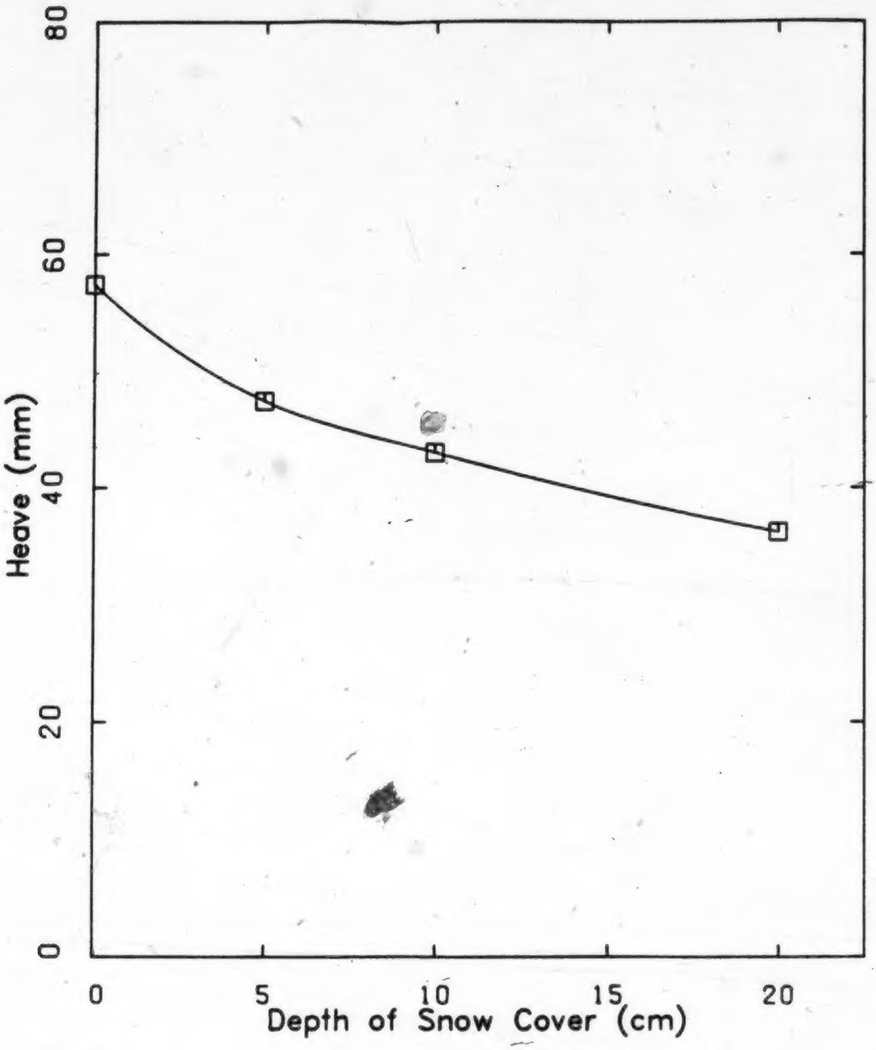


Figure 5.2 Comparison between one and two dimensional analytical models



(Insulation = 1.8 m x 5cm)

(SP=120 x 10^{-5} mm^2/s °C, FI=1000 °C days)

Figure 5.3 Influence of snow cover outside of the building on the magnitude of frost heave.

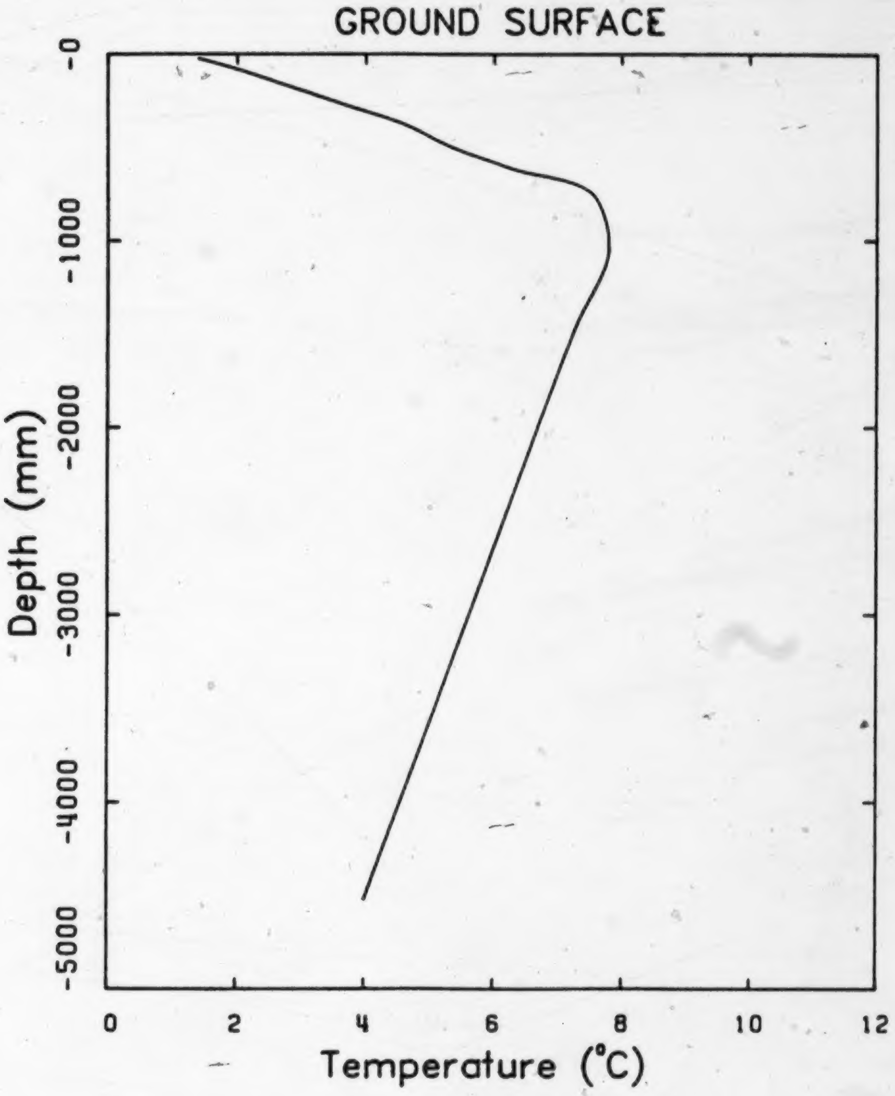


Figure 5.4 Typical ground temperature distribution before the freezing period.

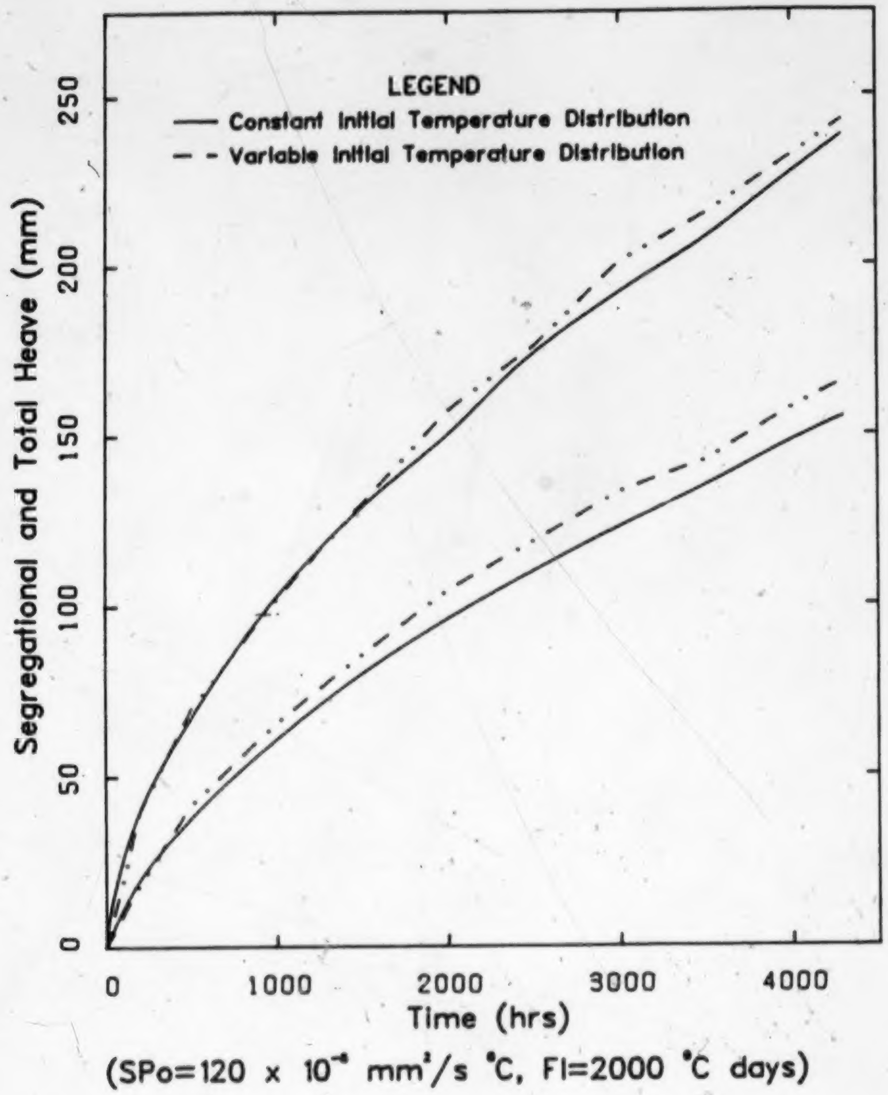
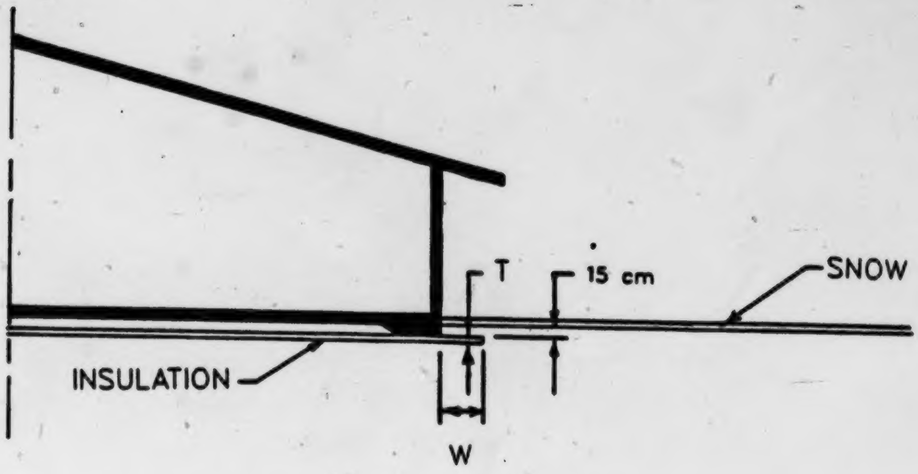
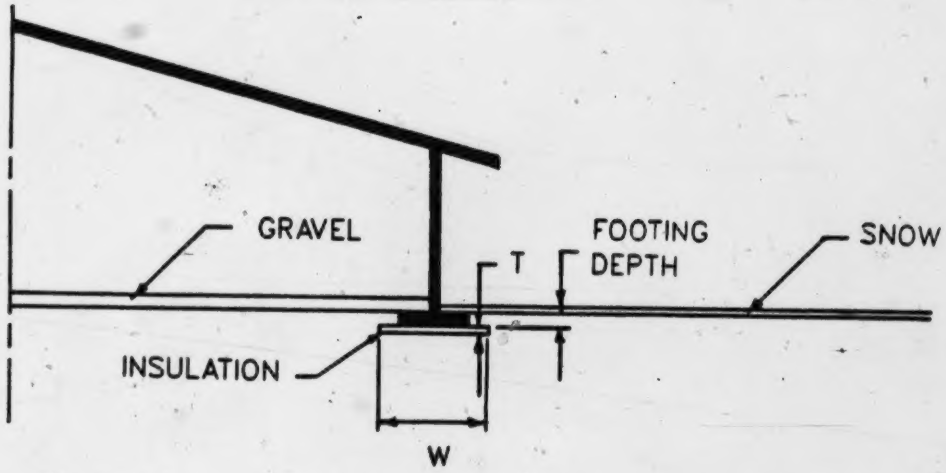


Figure 5.5 Influence of initial ground temperature on the magnitude of frost heave.


T
15 cm
SNOW
INSULATION
W

INSULATION UNDER THE ENTIRE BUILDING


GRAVEL
T
FOOTING
DEPTH
SNOW
INSULATION
W

INSULATION UNDER THE FOOTING

Figure 5.6 Insulation configurations analyzed.

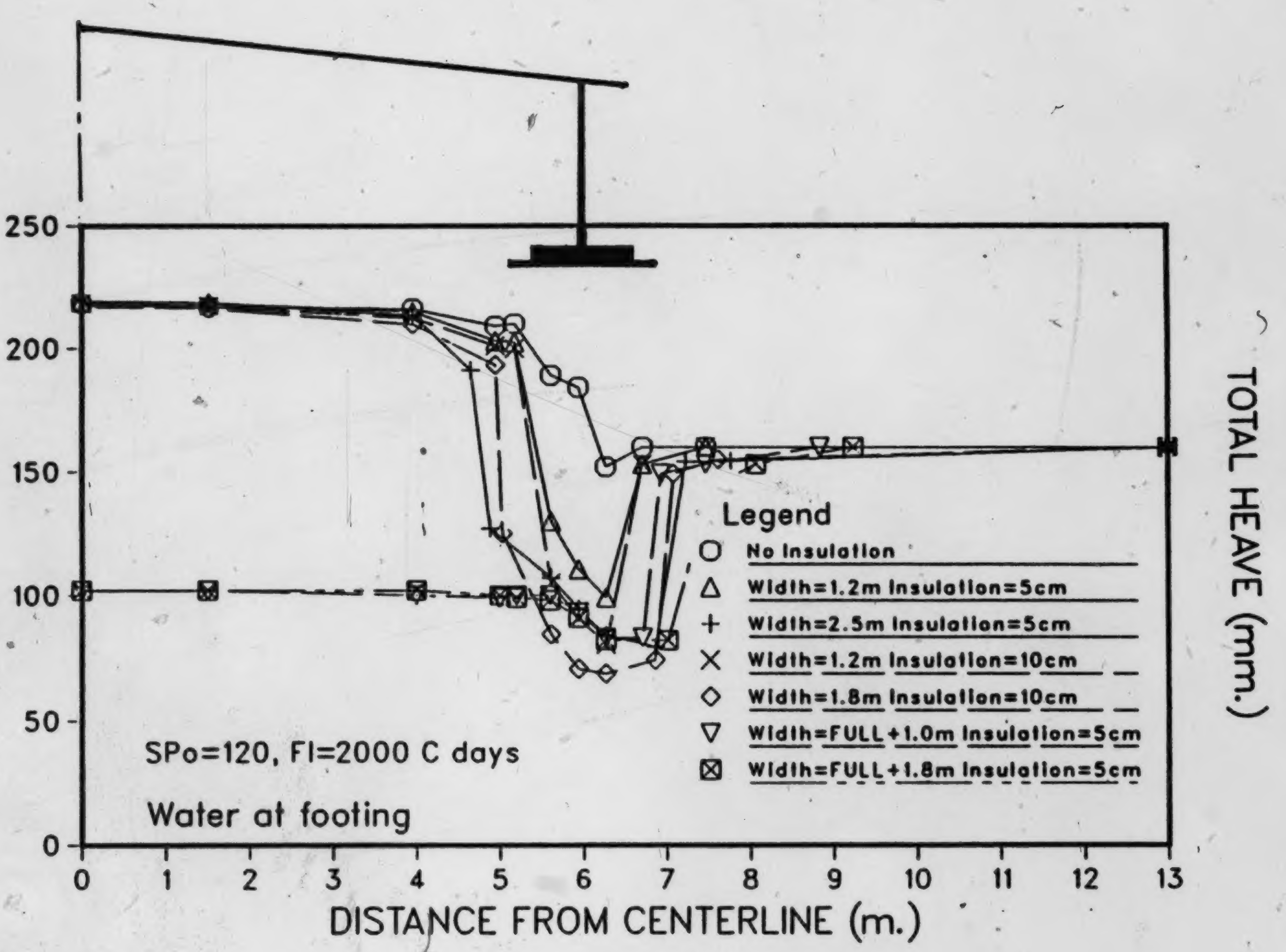


Figure 5.7 Distribution of frost heave under an unheated building.

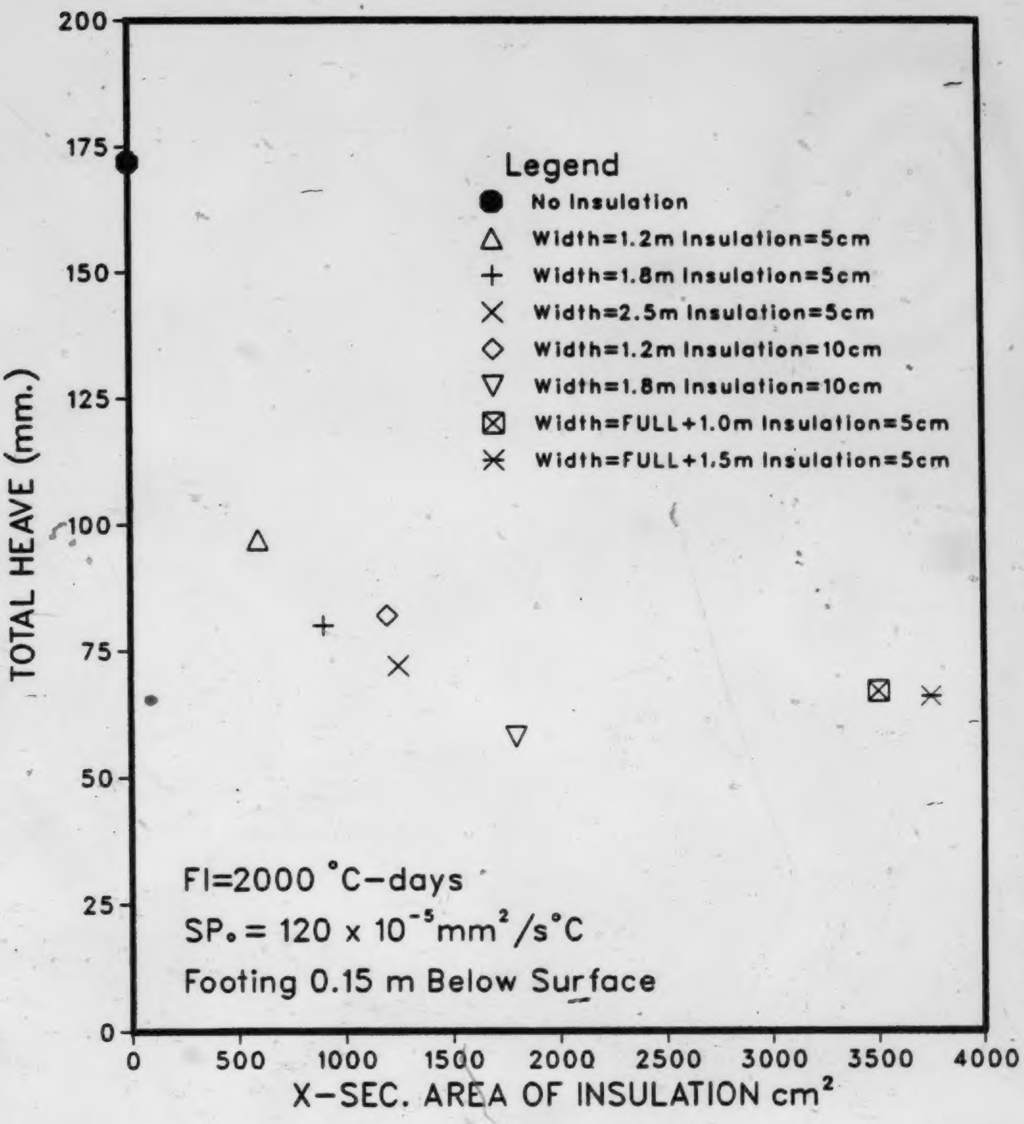


Figure 5.8 Effectiveness of Insulating layers.

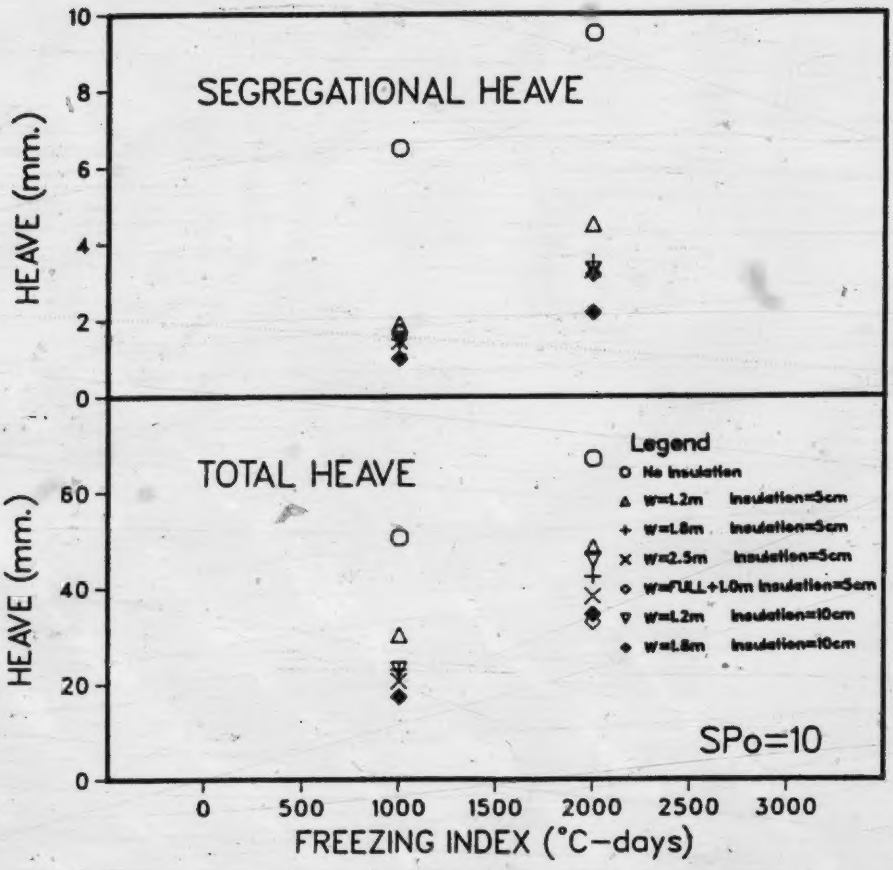


Figure 5.9 Heave versus freezing index for insulated footings at the ground surface $SP_0 = 10 \times 10^{-5} mm^2/s°C$

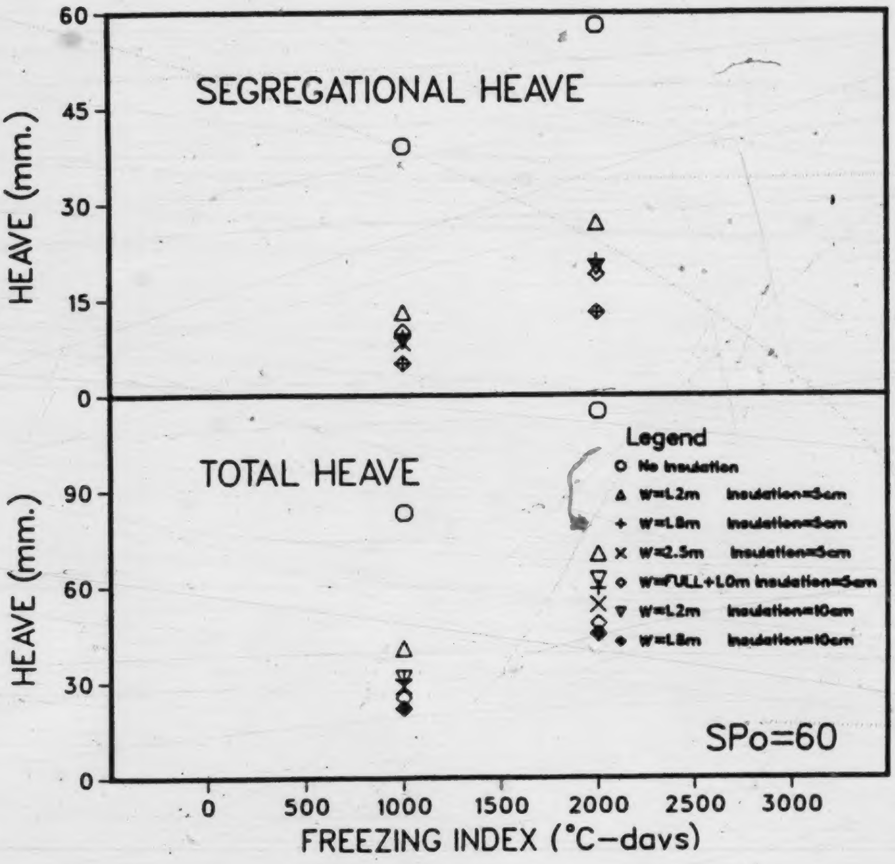


Figure 5.10 Heave versus freezing index for insulated footings at the ground surface $SP_0 = 60 \times 10^{-5} mm^2/s°C$

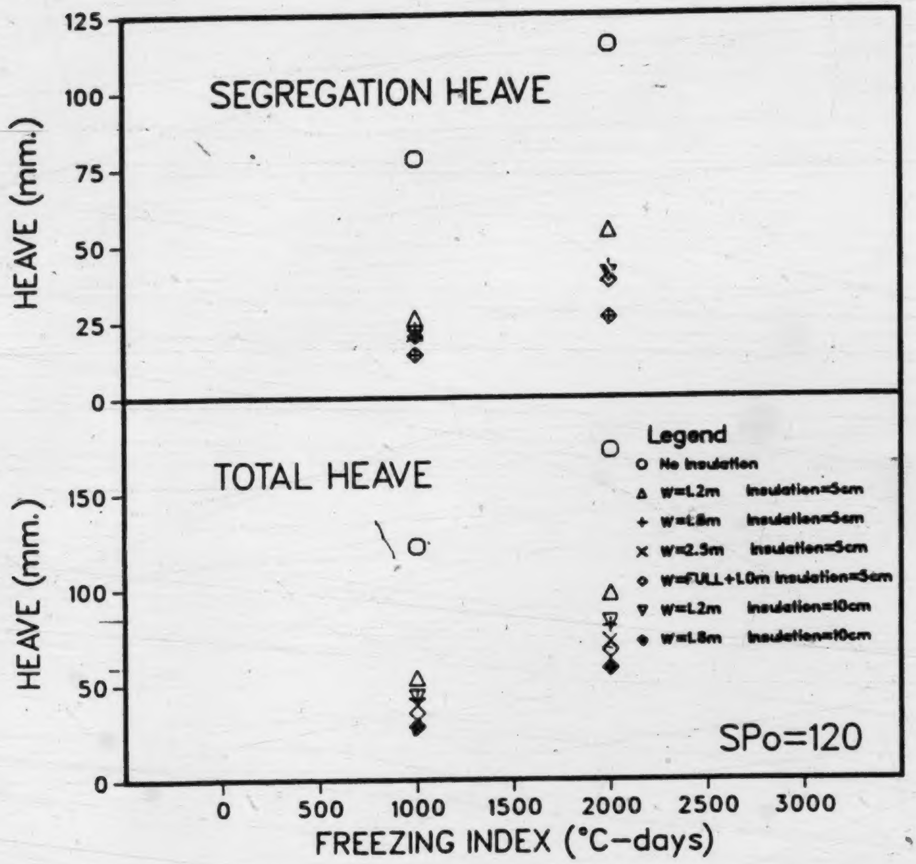


Figure 5.11 Heave versus freezing index for insulated footings at the ground surface $SP_0 = 120 \times 10^{-5} mm^2/s°C$

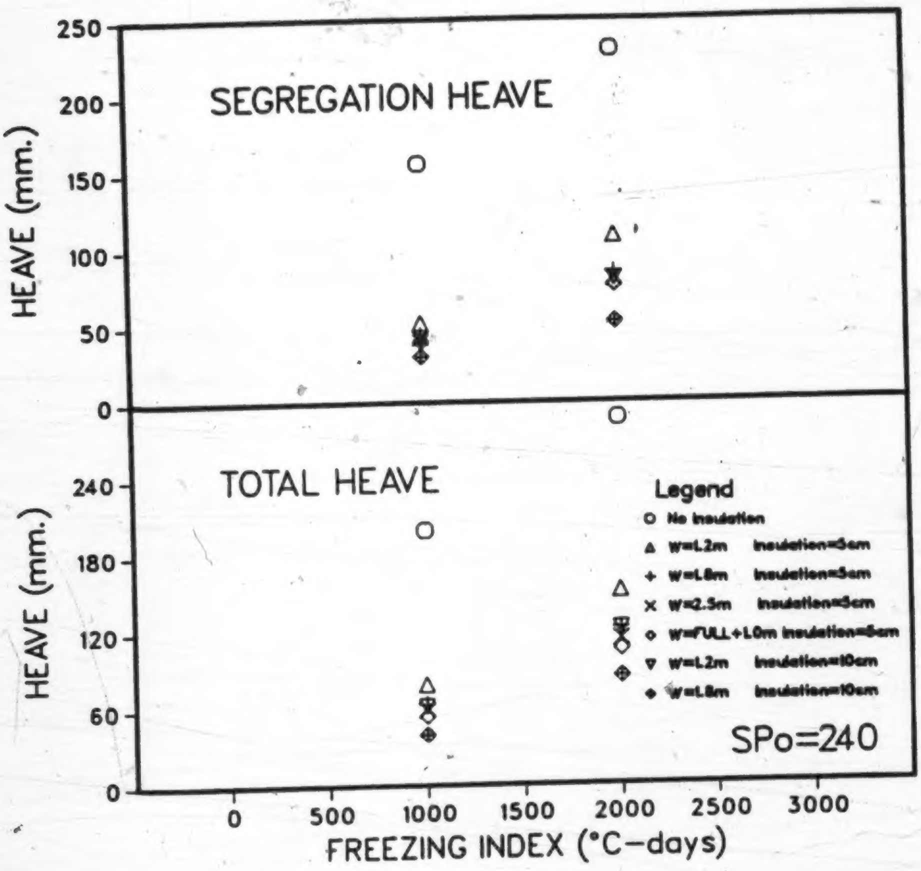


Figure 5.12 Heave versus freezing index for insulated footings at the ground surface $SP_0 = 240 \times 10^{-5} \mathrm{mm}^2/\mathrm{s}^\circ\mathrm{C}$

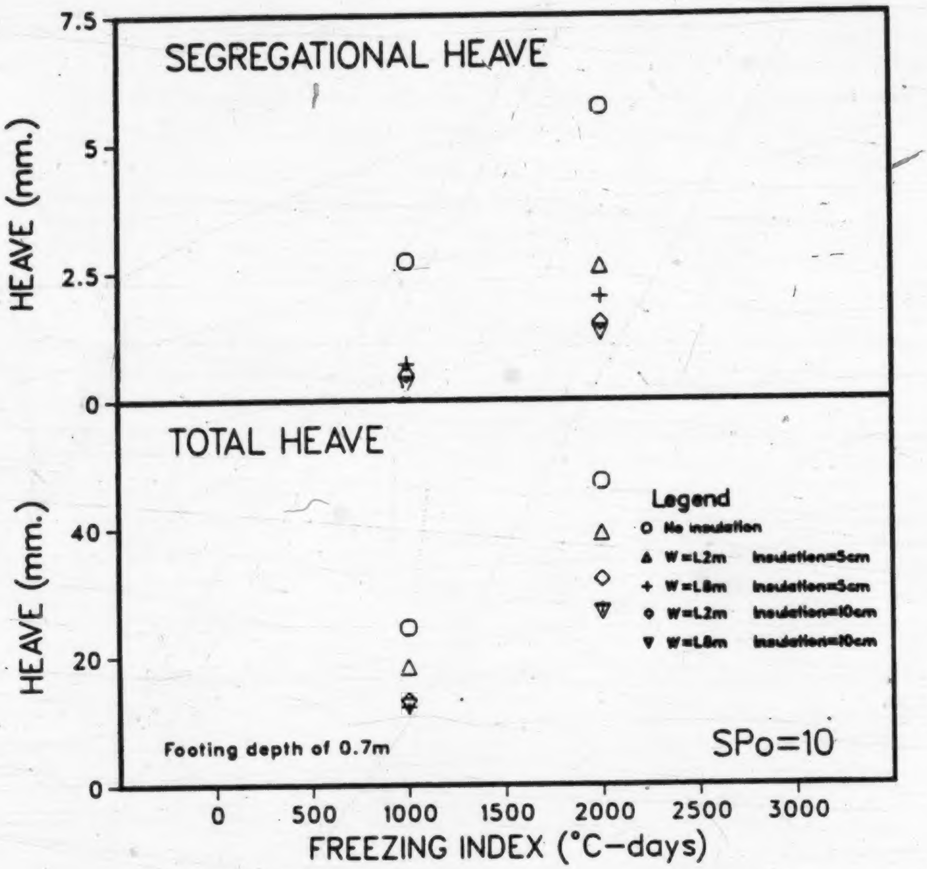


Figure 5.13 Heave versus freezing index for insulated footings at a depth of 70 cm below the ground surface $SP_0 = 10 \times 10^{-3} mm^2/s°C$

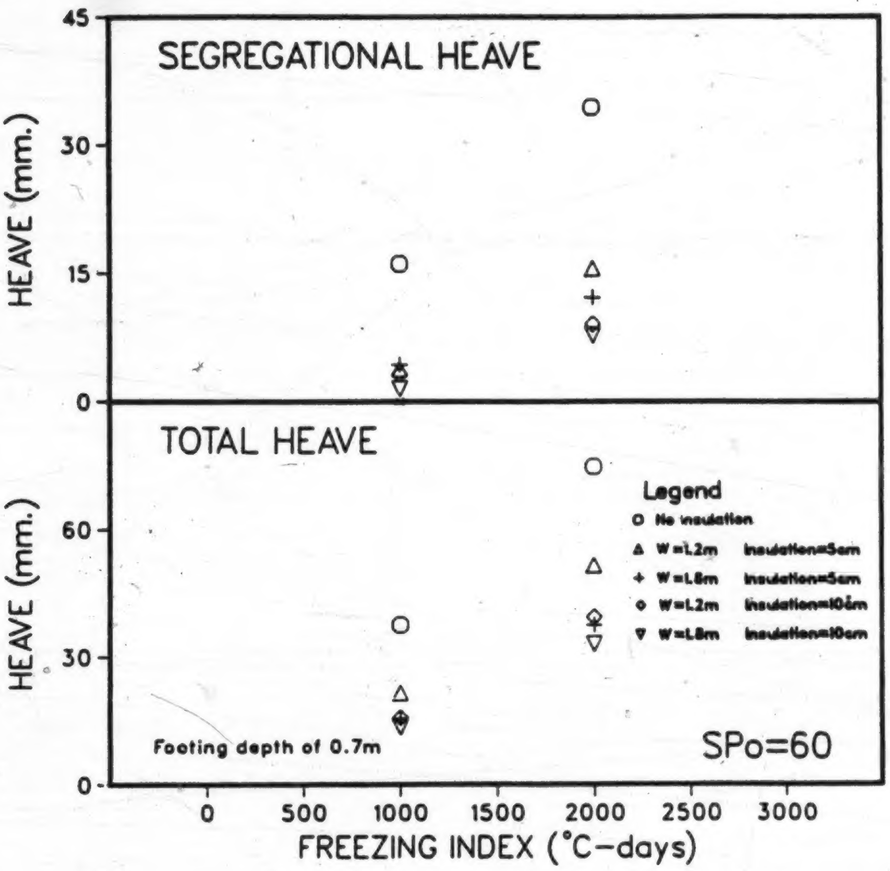


Figure 5.14 Heave versus freezing index for insulated footings at a depth of 70 cm below the ground surface SP_0 = 60 x $10^{-5}mm^2/s°C$

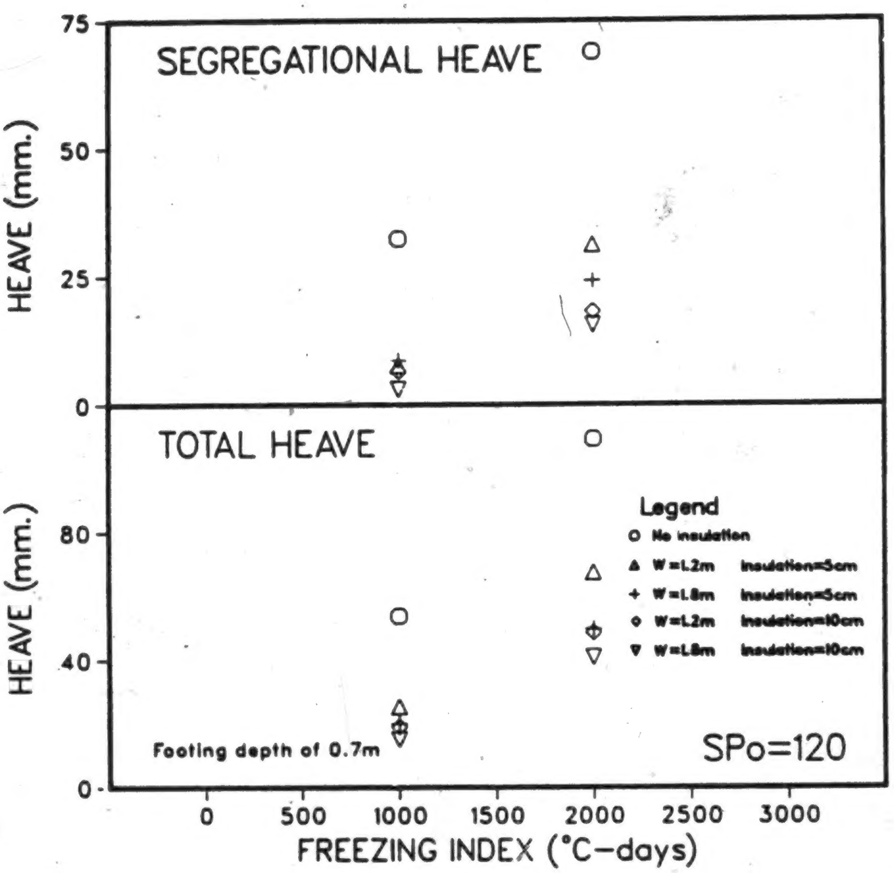


Figure 5.15 Heave versus freezing index for insulated footings at a depth of 70 cm below the ground surface SP_0 = 120 x $10^{-3}mm^2/s°C$

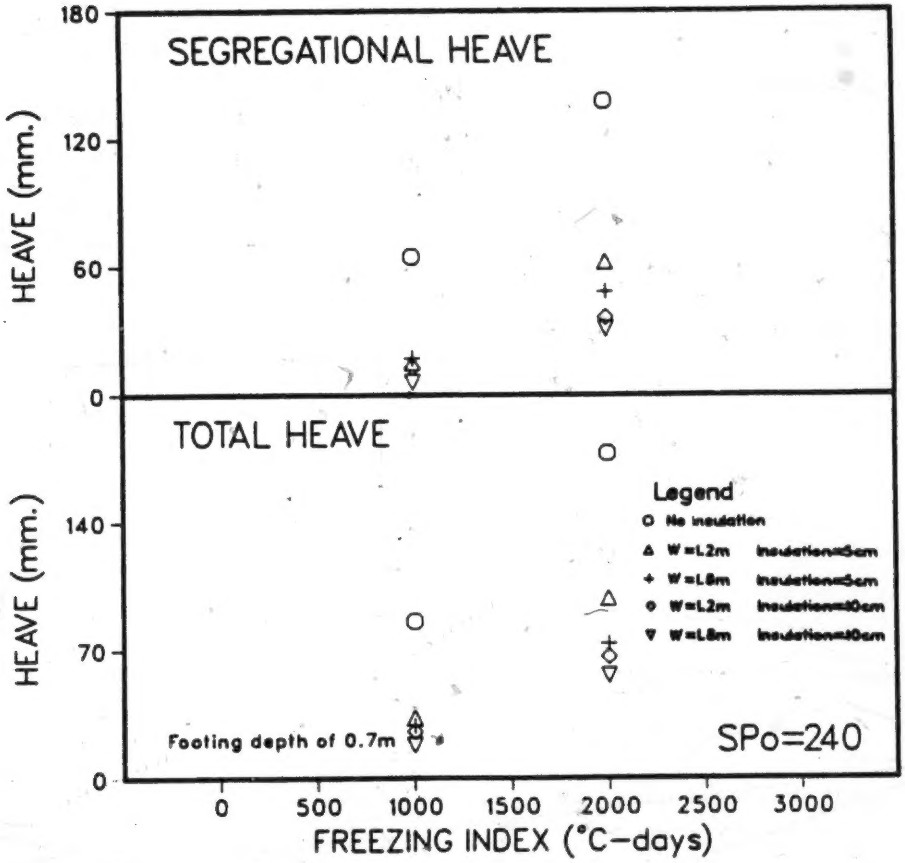


Figure 5.16 Heave versus freezing index for insulated footings at a depth of 70 cm below the ground surface SP_0 = 240 x 10^{-5}mm^2/s°C

6.0 SUMMARY AND CONCLUSIONS

6.1 Summary

The objective of this study was to provide a basis for a design manual on the control of frost heave under unheated buildings.

This objective was met by producing charts that enable the magnitude of frost heave to be predicted for particular situations. The magnitude of heave is dependent on the segregation potential of the soil, the climatic conditions and the depth of the water table. The soil type, soil permeability and the snow cover also influence the magnitude of heave.

It was found that frost heave could be controlled through the use of insulating layers. The quantity of insulation required in any particular case is dependent on the allowable deformation of the structure, the segregation potential of the soil, the water table depth and the climatic conditions.

The segregation potential of a soil is dependent of the percentage of clay in a soil and the mineralogy of the clay. Little clay is needed to produce a potentially dangerous segregation potential. Since no definite correlation between segregation potential and soil properties was achieved, the best way to estimate the segregation potential of a soil is by conducting laboratory freezing experiments.

6.2 Conclusions

From this analysis several conclusions are made

1. The major factors that influence the magnitude of heave are the freezing index, the segregation potential of the soil and the water table depth.
2. The original Konrad model can be simplified for the field case by making assumptions regarding the suction at the frost front and the rate of cooling.
3. From the currently available data there is no adequate method of estimating the segregation potential of a soil from standard soil index properties.
4. Insulating layers can effectively reduce the magnitude of heave for most climatic and soil conditions.

6.3 Recommendations

The results presented in this thesis should be verified with field data. This would entail measuring frost heave, climatic conditions and the depth of the water table for several field cases. The segregation potential of the soil would be determined by laboratory freezing tests. This would verify the assumption that the segregation potential measured in the laboratory accurately reflects the segregation potential in the field.

Research is needed to accurately predict the segregation potential of a soil from its soil properties. The influence of soil structure on segregation potential should be examined. This would enable a standardized procedure to be proposed for testing remolded samples so that they reflect the important freezing properties of an insitu soil.

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APPENDIX A.

Climatic Data for Canadian Cities.

Table A.1
Climatic Data for Selected Canadian Cities

City	Freezing Index Mean (°C-days)	Freezing Index Design (°C-days)	Return Period (yrs)	Average Snow Cover (cm)
Vancouver	45	236	44	0.0
Kamloops	463	798	30	3.8
Kelowna	463	638	12	-
Edmonton	1470	2173	44	12.7
Calgary	1168	1792	97	3.1
Saskatoon	1977	2669	39	10.2
Regina	1900	2889	87	13.7
Winnipeg	1920	2496	43	14.2
Thunder Bay	1532	1974	40	-
Sudbury	1418	1656	27	31.5
Ottawa	1058	1337	42	17.3
Toronto	638	834	42	3.2
Fredericton	896	1177	30	15.2
Charlottetown	736	1024	36	12.2
Shearwater	442	621	37	2.5
St. Johns	483	829	39	14.2
Niagara Falls	423	664	32	-
Quebec City	1191	1545	37	41.1
Montreal	958	1238	38	23.9
Trois Rivieres	1164	1401	45	-

Note - Design freezing index taken as the coldest winter over a the last 10 year period. From this data a relationship between the mean freezing index and the design freezing index can be developed.

$$DFI = 100 + 1.29 * MFI$$

where

DFI = design freezing index (°C-days)

MFI = mean freezing index (°C-days)

Note - Average snow cover is the average snow cover of the freezing season. It is measured in unsheltered areas.

APPENDIX B.

One Dimensional Model - Program, Input and Output.

```
C       **********************************************************
C       **                                                      **
C       **     ONE DIMENSIONAL FROST HEAVE BY THE KONRAD MODEL  **
C       **                                                      **
C       **********************************************************
C       *  PROGRAM TO SIMULATE THE ONE-DIMENSIONAL UNSTEADY HEAT FLOW
C          IN A FREEZING SOUL AND TO CALCULATE THE HEAVE WITH TIME AS
C          WELL AS THE ICE CONTENT PROFILE.
C       *  THIS PROGRAM CALCULATES THE THICKNESS OF THE FINAL ICE
C          LENS DURING A RETREATING FROST FRONT FOR FIXED TEMPERATURE
C          BOUNDARY CONDITIONS.
C       *  THE CRANK-NICHOLSON FINITE DIFFERENCE METHOD IS USED.
C          A FIXED GRID WITH A SUPPLEMENTARY NODE AT THE INTERFACE
C          PERMITS THE MOVING BOUNDARY SITUATION.
C       *  FROZEN AND UNFROZEN SOIL THERMAL PROPERTIES ARE CONSIDERED
C          AS INDEPENDENT WITH TEMPERATURE.  WATER REMAINING UNFROZEN
C          BELOW ZERO DEGREES CELCIUS IS TAKEN INTO ACCOUNT BY THE
C          LUMPED PARAMETER EPS.
C       *  THE PHYSICS OF WATER MIGRATION TO THE SEGREGATION-FREEZING
C          FRONT HAS BEEN ADDED. THE SEGREGATION POTENTIAL IS DEFINED
C          AS THE RATIO OF THE WATER INTAKE RATE AND THE TEMPERATURE
C          GRADIENT IN THE FROZEN FRINGE IS DEPENDENT ON THE RATE OF
C          COOLING OF THE FRINGE AND THE SUCTION AT THE FROST FRONT
C       *  THE CHARACTERISTIC FREEZING SURFACE OF A GIVEN SOIL IS
C          OBTAINED FROM EXPERIMENTAL DATA.
C       *  THE PROGRAM CAN INCORPORATE ANY SPECIFIED COLD AND WARM
C          SIDE TEMPERATURE VARIATION.  NO LOAD IS APPLIED TO THE
C          SAMPLE IN THE FOLLOWING MODEL.  HOWEVER, A DIFFERENT
C          CHARACTERISTIC FREEZING SURFACE CORRESPONDING TO THE
C          DESIRED SURCHARGE IS SUFFICIENT FOR PREDICTION OF FROST
C          HEAVE UNDER EXTERNAL LOADS WITH THIS MODEL
C
C       RUN COMMAND: $RUN KONRAD OBJ 5=1/P 6=0/P1 7=0/P2
C
C
C
C
C
C
C       AREA    CROSS-SECTIONAL AREA                          [ CM**2 ]
C       CAF     (VOLUMETRIC) HEAT CAPACITY, FROZEN
C       CAU     (VOLUMETRIC) HEAT CAPACITY, UNFROZEN
C       CF      THERMAL CONDUCTIVITY, FROZEN SOIL    [MILLICAL/C/MM/S]
C       CFE     THERMAL CONDUCTIVITY, FR SOIL & ICE  (MILLICAL/C/MM/S)
C       CFR     THERMAL CONDUCTIVITY, FROZEN FRINGE  [MILLICAL/C/MM/S]
C       CI      THERMAL CONDUCTIVITY, ICE            (MILLICAL/C/MM/S)
C       CU      THERMAL CONDUCTIVITY, UNFROZEN SOIL  [MILLICAL/C/MM/S]
C       DH      INCREMENTAL HEAVE                               [ MM ]
C       DT      TIME STEP INCREMENT                        [ SECONDS ]
C       EPS     FRACTION OF IN-SITU WATER THAT FREEZES
C       EPSIL,  MIN. COOLING RATE, OTHERWISE CALCS CONTINUE  [ C/HR ]
C       F       FRACTION UNFROZEN IN THE PARTIALLY FROZEN SEGMENT
C       FG      STOPS CALCS WHEN STEADY STATE EXISTS IF FG>2
C       GRADT   TEMPERATURE GRADIENT                          [ C/MM ]
C       HINT    INTAKE HEAVE                                    [ MM ]
C       HR      TIME                                            [ HR ]
C       HRC     "DT" IN HOURS INSTEAD OF SECONDS                [ HR ]
C       HRL     A TRIGGER TIME FOR OUTPUT(                      [ HR ]
C       HRL2    A TIME LIMIT                                    [ HR ]
C       HT      TOTAL HEAVE                                     [ MM ]
C       KEY     TRIGGER TO USE A SINUSOILDAL TEMP. DISTRIBUTION
C       NI      NUMBER OF SEGMENTS
C       NP      NUMBER OF COMPLETELY UNFROZEN LENGTHS
C       P       SUCTION                                [ METRES H2O ]
C       PE      OVERBURDEN PRESSURE AT THE FROST FRONT         ( MPa )
C       PEI     INITIAL OVERBURDEN PRESSURE                    ( MPa )
C       PERMU1  UNFROZEN PERMEABILITY                         [ MM/S ]
C       PERMU2  UNFROZEN PERMEABILITY OF SECOND MATERIAL      [ MM/S ]
C       POR     POROSITY
C       RC      RATE OF COOLING                               [ C/HR ]
C       RCC     LIMITTING RATE OF COOLING                     [ C/HR ]
C       SP      SEGREGATION POTENTIAL                   [ MM**2/(C*S)]
C       TC      APPLIED COLD TEMPERATURE                   [ CELCIUS ]
C       TD      DELTA TIME                                 [ SECONDS ]
C       TS      SEGREGATION FREEZING TEMPERATURE           [ CELCIUS ]
C       TVOL    TOTAL VOLUME                                    [ ML ]
C       TW      APPLIED WARM TEMPERATURE                   [ CELCIUS ]
C       TCI     INITIAL COLD TEMPERATURE                   ( CELCIUS )
C       TCMAX   MAXIMUM COLD SIDE TEMP FOR SINE TEMP DIST ( CELCIUS )
C       W       HEAT FLOW                               [ MILLIWATTS ]
C       X       FROZEN THICKNESS                                [ MM ]
C       XS      FROZEN AND HEAVED HEIGHT                        ( MM )
C       V       INFLOW VELOCITY                               [ MM/S ]
C       Z       UNFROZEN LENGTH                                 [ MM ]
C       ZU      INITIAL UNFROZEN LENGTH                         [ MM ]
C       ZU2     LENGTH OF MAT'L WITH PERMU2, IN SERIES WITH PERMU1
C       XX      FACTOR OF SP SURFACE
C
C
C
      REAL A(2000),B(2000),C(2000),D(2000),AA(2000),BT(2000),
     *      DD(2000),DV(200),ZA(200),DWC(200),H(200),HS(200)
      REAL TWARM(2000),TCOLD(2000),YO(2000),S(200),XP(200),FY(200)
C
```

```
C........................ENTER THE PARAMETERS NECESSARY FOR SOLUTION
C
      READ(5,1) KEY,NI,DT,EPSIL
      READ(5,2) TC,TW,CF,CFR,CU,CAF,CAU
      READ(5,3) ZU,AREA,POR,EPS,HRL
      READ(5,4) ZU2,PERMU1,PERMU2,SAT
      READ(5,5) TCMAX
      READ(5,6) HRL2
      READ(5,7) PS,TS,RCC,CUE,CUI,TD
      READ(5,8) XX,WT,PEI
    1 FORMAT(2I5,2F10.6)
    2 FORMAT(2F5.0,5E10.0)
    3 FORMAT(5F10.2)
    4 FORMAT(F10.2,3E10.3)
    5 FORMAT(F10.2)
    6 FORMAT(1F10.2)
    7 FORMAT(6F10.4)
    8 FORMAT(3F10.3)
C
      WRITE(6,55) ZU,ZU2,POR,SAT,EPS,CF,CFR,CU,PERMU1,PERMU2,NI,TC
     +,TCMAX,TW,WT,XX
   55 FORMAT('1',20X,'DATA INPUT:'/10X,
     +'INITIAL UNFROZEN LENGTH IS:',T50,F10.4,' MM'
     +/10X,'SATURATED LENGTH IS:',T50,F10.4,' MM'
     +/10X,'POROSITY IS :',T50,F10.4
     +/10X,'DEGREE OF SATURATION IN UNSAT. SOIL :',T50,F10.4
     +/10X,'PHASE CHANGE FOR :',T50,F10.4,' OF INITIAL WC'
     +/10X,'FROZEN THERMAL CONDUCTIVITY IS :',T50,F10.4,
     +                                           ' MILLICAL/C/MM/S'
     +/10X,'FROZEN FRINGE THERMAL CONDUCTIVITY IS :',T50,F10.4,
     +                                           ' MILLICAL/C/MM/S'
     +/10X,'UNFROZEN THERMAL CONDUCTIVITY IS :',T50,F10.4,
     +                                           ' MILLICAL/C/MM/S'
     +/10X,'UNSATURATED PERMEABILITY IS :',T50,1PE10.3,' MM/S'
     +/10X,'SATURATED PERMEABILITY IS :',T50,1PE10.3,' MM/S'
     +/10X,'NUMBER OF SEGMENTS :',T50,I10
     +/10X,'COLD SIDE TEMPERATURE :',T50,0PF10.4,' CELCIUS'
     +/10X,'SINUSOIDAL TEMP. TCMAX :',T50,0PF10.4,' CELCIUS'
     +/10X,'WARM SIDE TEMPERATURE :',T50,F10.4,' CELCIUS'
     +/10X,'WATER TABLE IS :',T50,F10 4,'MM BELOW THE SURFACE'
     +/10X,'FACTOR OF SP-PU-RC SURFACE IS :',T50,F10.4)
C
C                                           ... INITIAL NODAL SEPARATION
      DZ=ZU/NI
      WRITE(6,51)DT,DZ
   51 FORMAT(//,10X,'THE TIME STEP IS :',T50,F10.2,' SECONDS'
     +/10X,'THE NODE SEPARATION IS :',T50,F10.4,' MM')
      WRITE(7,7777)
 7777 FORMAT('1')
C
C.....BETA= ALPHA*DT/DX**2   WHERE ALPHA*D2U/DX**2 = DU/DT
C
      BETA=DT*CU/(DZ*DZ*CAU)
C
C                *** * * INITIALIZE THE UNKNOWNS * * ***
      SP=0.
      PU1=0.
      GRADT=0.
      W=0.
      H(1)=0.
      DF=0.
C                                        .......THERMAL CONDUCTIVITY OF ICE
      CI=0.5
      RC=3.
      TCI=TC
      V=0.000
      HR=0.
      TIME=0.
      TVOL=0.
      DFM=0.
      HINT=0.
      HT=0.
      Z=ZU
      X=0.
      TPR1=0.5
      TPR2=10.
      TPR3=110.
      TPR4=2.
      TP4=2.
      TPR5=10.
      TP5=10.
      PORSAT=POR
      KO=1
      KOU=1
      JO=1
      TPR5=HLIM*0.1
      P=0.
      WRITE(6,150)
  150 FORMAT('1',//,'      TIME     TC    UNFROZEN FROZEN COOLING ',
     +'SUCTION    SP     GRAD T   INFLOW   TOTAL   INTAKE   TOTAL ',
     +' POWER'/15X,' LENGTH  LENGTH   RATE',10X,'  (MM**2) ',5X,
     +'VELOCITY  VOLUME   HEAVE',
     +'    HEAVE'/'+',T46,'______'
     +/'      (HR)    (C)    (MM)      (MM)    (C/HR)   (M H2O)   ( S*C ) ',
     +' (C/MM)    (MM/S)     (ML)     (MM)     (MM)  (MILLI-W)')
C
C     ****************************************************************
C     **                                                            **
            CALL OUTPUT(HR,TC,Z,X,RC,P,DP,GRADT,V,TVOL,HINT,HT,W)
C     **                                                            **
C     ****************************************************************
      TIME=TIME+DT
      ZM=ZU
      CK=CF-CU
      XO2=ABS((DT*CK*2.*TC)/(EPS*POR*79.6))
      XO=SQRT(XO2)
      DH=0.09*POR*EPS*XO
C                                             ... TOTAL UNFROZEN LENGTH
      Z=ZU+DH-XO
C
      HT=DH
C
      K=NI-1
      M=1
      MM=1
C                                       ... INITIALIZES SOIL TEMP TO TW !!!
         DO 13 I=1,K
   13    TWARM(I)=TW
C                                          ...FIRST NODE SET TO 0.5*TCOLD
      TCOLD(1)=TC*0.5
      TCOLD(2)=0.
C
C
C     <<<<<<<<<<<<<<<<< BEGINNING OF THE TIME LOOP >>>>>>>>>>>>>>>>>>
C
C
 1000 TIME=TIME+DT
      HR=TIME/3600.
C
C                             ........UNSTURATED SOIL
C
      UNSAT=ZU-ZU2+HT
      IF(X.GT.UNSAT) GO TO 18
      POR=PORSAT*SAT
      GO TO 19
   18 POR=PORSAT
C
C       *** * * SOLVE FOR TEMPERATURES IN THE UNFROZEN SOIL * * ***
C                                           NUMBER OF UNFROZEN SEGMENTS
   19 NP=Z/DZ
C                                    ... ADDITIONAL FRACTION OF A SEGMENT
      F=Z/DZ-NP
      N=NP
C                                     ... SET BOUNDARY NODE TEMP. TO ZERO
      TWARM(N+1)=0.
      NB=N-1
      A(1)=2. +2.*BETA
      B(1)=-BETA
      C(1)=0.
      D(1)=2.*BETA*TW+(2.-2.*BETA)*TWARM(1)+BETA*TWARM(2)
C
         DO 14 I=2,NB
         A(I)=2. +2.*BETA
         B(I)=-BETA
         C(I)=-BETA
   14    D(I)=BETA*TWARM(I-1)+(2.-2.*BETA)*TWARM(I)+BETA*TWARM(I+1)
C
      B(N)=0.
      A(N)=BETA+F
      C(N)=-BETA*F/(1.+F)
      D(N)=BETA*F*TWARM(N-1)/(1.+F)+(F-BETA)*TWARM(N)
C
C     ****************************************************************
C     **                                                            **
                        CALL GAUSEL(A,B,C,D,N)
C     **                                                            **
C     ****************************************************************
C
C                                                ... SET WARM TEMPS TO C(I)
         DO 16 I=1,N
   16    TWARM(I)=C(I)
      IF(HR.GE.10) GO TO 612
C                             ... WRITE TEMPS EVERY TP4 HOURS FOR TEN HOURS
      IF(HR.GE.TP4) GO TO 610
      GO TO 800
  610 TP4=TP4+2.
C                                        ... WRITE WARM TEMPS EVERY TP4 HOURS
  613 WRITE(7,611)HR,(TWARM(I),I=1,N)
  611 FORMAT(///' ELAPSED TIME =',F10.3,' HOURS'//' TEMPERATURES ',
     +10(/8F8.2))
      GO TO 800
  612 IF(HR.LT.TP6) GO TO 800
      TP6=TP6+50.
C                                            ... WRITE TEMPS EVERY TP6 HOURS
      GO TO 613
C                                ... UNFROZEN THERMAL GRADIENT OVER 1+ SEGMENTS
  800 DERTU=(TWARM(N-1))/((1.+F)*DZ)
      ST=K*ZU/NI
C
C                   ... COLD SIDE TEMP FOR SINUSOIDAL TEMP VARIATION
C
```

```
      IF(KEY.GT.1) GO TO 20
      TC=(SIN(3.1416*HR/HRL)*TCMAX)+TCI
C
C                  ... TRANSFER TO 22 IF MORE THAN ONE SEGMENT IS FROZEN
C
   20 IF(2.LE.ST) GO TO 22
      IF(M.GT.2) GO TO 29
      IF(M.GT.1) GO TO 23
      H(1)=H(1)+DH
C                                     ... FROZEN LENGTH OF FIRST SEGMENT
      DY(1)=DZ+H(1)-F*DZ
C                                            ... FROZEN THERMAL GRADIENT
      DERTF=ABS(TC/DY(1))
C                                     ... FROZEN FRINGE THERMAL GRADIENT
      GRADT=CF*DERTF/CFR
C                                    ... TRANSFER TO THE CONTINUITY CALCS
      GO TO 50
C
C
   22 IF(M.GT.1) GO TO 21
      DY(1)=DZ+H(1)
      GO TO 21
   21 DWC(M)=91.74*H(M)/((1.-POR)*DZ*2.7)
      DY(M)=DZ+H(M)
C
C
      K=K-1
      M=M+1
      MM=M-1
   29 HS(MM)=HS(MM-1)+H(MM)
C
   23 HS(1)=H(1)
      H(M)=HT-HS(MM)
      DY(M)=DZ+H(M)-F*DZ
      G=DY(M)/DY(M-1)
      MP=NI-1-MP
      IF(MP.LE.1) GO TO 31
      N=MP
      NK=N-1
C
C
  510 TCOLD(N+1)=0.
          DO 26 I=1,NK
          DD(I)=DY(I)+DY(I+1)
          BT(I)=CF*DT/(CAF*DD(I))
          AA(I)=BT(I)*((1./DY(I+1))+(1./DY(I)))
          C(I)=-BT(I)/DY(I)
          B(I)=-BT(I)/DY(I+1)
   26     A(I)=AA(I)+1.
      C(1)=0
      D(1)=(+2.*BT(1)/DY(1))*TC-(AA(1)-1.)*TCOLD(1)-B(1)*TCOLD(2)
      IF(NK.LE.1) GO TO 37
          DO 27 I=2,NK
   27     D(I)=-C(I)*TCOLD(I-1)-(AA(I)-1.)*TCOLD(I)-B(I)*TCOLD(I+1)
   37 D(N)=0.
C                                           BETA FACTOR FOR FROZEN SOIL
C
      BETAF=(CF*DT)/(CAF*DY(N-1)*DY(N-1))
      A(N)=BETAF+G
      C(N)=-BETAF*G/(1.+G)
      D(N)=BETAF*G*TCOLD(N-1)/(1.+G)+(G-BETAF)*TCOLD(N)
C
C     ****************************************************************
C     **                                                            **
                     CALL GAUSEL(A,B,C,D,N)
C     **                                                            **
C     ****************************************************************
C
          DO 28 I=1,N
   28     TCOLD(I)=C(I)
      IF(HR.GE.10.) GO TO 712
      IF(HR.GE.TPR4) GO TO 710
      GO TO 700
  710 TPR4=TPR4+2.
C                                              ... WRITE COLD TEMPERATURES
  713 NREVRS=N+1
      WRITE(7,711)(TCOLD(NREVRS-I),I=1,N)
  711 FORMAT(8F8.2)
      GO TO 700
  712 IF(HR.LT.TPR6) GO TO 700
      TPR6=TPR6+50.
      GO TO 713
C
C
C                                              ... FROZEN THERMAL GRADIENT
  700 DERTF=ABS(TCOLD(N-1)/(DY(N)+DY(N+1)))
C                                       ... FROZEN FRINGE THERMAL GRADIENT
      GRADT=CF*DERTF/(SP*79.6+CFR)
C
C
      GO TO 50
C                                              ... FROZEN THERMAL GRADIENT
   31 DERTF=ABS(TC/(DY(1)+DY(2)))
C                                      .... FROZEN FRINGE THERMAL GRADIENT
```

```
          GRADT=CF*DERTF/(SP*79.6+CFR)
C
C
C
C...........SOLVE FOR CONTINUITY AT THE INTERFACE AND CALCULATE HEAVE
   60 HRC=DT/3600.
      IF(HR.GT.HRL2) GO TO 399
      IF(HR.GE.HRC) GO TO 399
      GO TO 453
C                                         ... KONRAD PHD THESIS, (EQ'N. 4.14)
  399 RC=(1800./DT)*(DERTF*(2*DX+DFM)-0.1)
      IF(RC.GT.00) GO TO 300
      IF(KOU.GT.2) GO TO 300
      RC=3.0
  300 DFM=0.1/DERTF
C                                               ... EQUIVALENT PERMEABILITY
  301 IF(Z.LE.ZU2) GO TO 395
      PERMU=Z/(((Z-ZU2)/PERMU1)+(ZU2/PERMU2))
      GO TO 398
  395 PERMU=PERMU2
  398 S(1)=0.
         DO 470 JI=1,9
C                                                     ... SUCTION   [ M H2O ]
         P=S(JI)
C     ************************************************************
C     **                                                        **
                CALL SURF(P00,P01,P05,P1,P2,P5,P10,P,SP,RC,XX,XS,PEI)
C
C     ************************************************************
         XP(JI)=SP
         IF(XP(1).LE.0.) GO TO 453
         WTZ=WT+HT-X
         IF (WTZ.GT.0.10) GO TO 469
         WTZ=.10
  469    FV(JI)=(XP(JI)*GRADT-(S(JI)*1000.*PERMU/WTZ))*1.E+06
         JIJ=JI+1
         S(JIJ)=S(JI)+1
  470    CONTINUE
      XP(9)=0.
C
            DO 471 JI=1,9
            IF(FV(JI).LT.0.) GO TO 472
  471       CONTINUE
C
  472 P=(FV(JI-1)*S(JI)-FV(JI)*S(JI-1))/(FV(JI-1)-FV(JI))
C
C     ************************************************************
C     **                                                        **
                CALL SURF(P00,P01,P05,P1,P2,P5,P10,P,SP,RC,XX,XS,PEI)
C
C     ************************************************************
C
C...........CALCULATE THE WATER FLUX AND FROST FRONT PENETRATION RATE
C
C                           NB: GRADT DERIVED FROM FROZEN THERMAL GRADIENT
  451 V=SP*GRADT
      R=DERTF/DERTU
C
C
      RS=CU/(CF-(79.6*SP))
C
C
C                                                ... LATENT HEAT POWER GAIN
      W=(CF*DERTF-CU*DERTU)*4.1868
C
C                             GO TO 1500 FOR RETREATING FROST FRONT PHASE
      IF(R.LE.RS) GO TO 1500
      GO TO 450
  453 V=0.
C                                                ... LATENT HEAT POWER GAIN
      W=(CF*DERTF-CU*DERTU)*4.1868
      JO=1
C                                          ... INCREMENTAL FROST PENETRATION
C
  450 DX=DT*(CF*DERTF-CU*DERTU-V*79.6)/(EPS*POR*79.6)
C     DX=TIME*<NET POWER/AREA FOR INSITU>/<INSITU LATENT HEAT/VOL>
      IF(DX.LT.0.)  GO TO 1500
C                                                     ... INC. INSITU HEAVE
      DHEX=0.09*EPS*POR*DX
C                                                     ... INC. INTRO. HEAVE
      DHIN=1.09*V*DT
C                                                     ... TOTAL INC. HEAVE
      DH=DHEX+DHIN
      HT=HT+DH
C                                                    .. TOTAL INTRO  HEAVE
      HINT=HINT+DHIN
C                                                    ... INCR  INTRO. WATER
      DVOL=V*DT*AREA*0.1
C                                                    ... TOTAL INTRO  WATER
      TVOL=TVOL+DVOL
C                                                    ... UNFROZEN HEIGHT
      Z=Z-DX
C                                                    ... FROZEN HEIGHT
      X=ZU+HT-Z
      C
            IF(RC.LT.0.) GO TO 35
            IF(RC.LE.RCC) GO TO 341
            GO TO 35
        341 KOU=KOU+1
            IF(KOU.LE.2) GO TO 35
      C                                               ... FRINGE + UNFROZEN HEIGHT
      C                                                 (NB: UNFR. GRADIENT USED)
            ZS=Z+(ABS(TS)/DERTU)
            XS=X+Z-ZS
      C                                                  ... COMPLETELY FROZEN
         35 IF(HR.GE.HRL) GO TO 1500
            IF(HR.GE.110.) GO TO 40
            IF(HR.GE.10.) GO TO 36
            IF(HR.GE.TPR1) GO TO 34
      C                                                    ... ANOTHER TIME STEP
            GO TO 1000
         34 TPR1=TPR1+0.5
      C                                        PRINT EVERY HALF-HOUR FOR 10 HR
      C     ***************************************************************
      C     **                                                             **
                 CALL OUTPUT(HR,TC,Z,X,RC,P,SP,GRADT,V,TVOL,HINT,HT,W)
      C     **                                                             **
      C     ***************************************************************
      C
            IF(RC.LE.EPSIL) GO TO 1500
            GO TO 1000
      C
         36 IF(HR.GE.TPR2) GO TO 38
      C                                                    ... ANOTHER TIME STEP
            GO TO 1000
         38 TPR2=TPR2+5
      C                                            PRINT EVERY HOUR AFTER 10 HR
      C     ***************************************************************
      C     **                                                             **
                 CALL OUTPUT(HR,TC,Z,X,RC,P,SP,GRADT,V,TVOL,HINT,HT,W)
      C     **                                                             **
      C     ***************************************************************
            IF(RC.LE.EPSIL) GO TO 1500
      C                                                    ... ANOTHER TIME STEP
            GO TO 1000
      C
         40 IF(HR.GE.TPR3) GO TO 42
      C                                                    ... ANOTHER TIME STEP
            GO TO 1000
      C
         42 TPR3=TPR3+50.
      C     ***************************************************************
      C     **                                                             **
                 CALL OUTPUT(HR,TC,Z,X,RC,P,SP,GRADT,V,TVOL,HINT,HT,W)
      C     **                                                             **
      C     ***************************************************************
      C
            IF(RC.LE.EPSIL) GO TO 1500
      C                                                    ... ANOTHER TIME STEP
            GO TO 1000
      C               *************************  END OF TIME INCREMENT **
      C
      C     ***************************************************************
      C     **                                                             **
       1500      CALL OUTPUT(HR,TC,Z,X,RC,P,SP,GRADT,V,TVOL,HINT,HT,W)
      C     **                                                             **
      C     ***************************************************************
      C
            WRITE(6,80)
         80 FORMAT(//,'RETREATING FROST FRONT PHASE')
      C
      C................FROST HEAVE DURING THE RETREATING FROST FRONT PHASE
            IF(FS.GT.2) GO TO 1505
            TIB=HR
            TIF=TIB+TD
            VO=V
            DH=0.
            DTIME=0.
            WRITE(7,72) DH, VO, DTIME
         72 FORMAT(6X,'DH= ',F10.2,6X,'VO= ',1PE10.4,3X,'DTIME= ',0PF10.1)
            HM=(CI*ABS(TC)*ZS/(CUE*TW))-(CI*XS/CF)
            HE=HM/40.
            DFF=(ZS-Z)/40.
         70 DH=DH+HE
            Z=Z+DFF
            IF(Z.GT.ZS) GO TO 32
            IF(HR.GT.HRL) GO TO 32
            DERTF=ABS(TC)/(XS+DH)
            DERTU=TW/2
      C                                         ... EFFECTIVE THERMAL CONDUCTIVITY
            CFE=(XS+DH)/((XS/CF)+(DH/CI))
            IF(HR.GT.TIF) GO TO 73
      C                                       ... INTERPOLATE ON UNFR. THERMAL K ??
            CU=CUI+((CUE-CUI)*(HR-TIB)/TD)
            GO TO 75
         73 CU=CUE
      C
         75 V=(DERTF*CFE-(DERTU*CU))/79.6
            IF(V.GT.0) GO TO 71
            V=0.
         71 DTI=2.*HE/(1.09*3600.*(VO+V))
      DTIME=DTIME+DTI
      HR=HR+DTI
      HT=HT+HE
      HINT=HINT+HE
      X=X+HE
C
      DVOL=HE*AREA/10.9
      TVOL=TVOL+DVOL
C
C     ***************************************************************
C     **                                                            **
            CALL OUTPUT(HR,TC,Z,X,RC,P,SP,GRADT,V,TVOL,HINT,HT,W)
C     **                                                            **
C     ***************************************************************
C
      WRITE(7,772)DH,V,DTIME
  772 FORMAT(8X,'DH= ',F10.2,7X,'V= ',1PE10.4,3X,'DTIME= ',0PF10.1)
      VO=V
      GO TO 70
 1505 WRITE(6,1501)
 1501 FORMAT(//,'          STEADY TEMPERATURE STATE HAS BEEN REACHED')
      WRITE(7,599)
  599 FORMAT('1'//16X,'LENGTH OF              INCREASE IN'/
     +16X,          'UNFROZEN SOIL          WATER CONTENT'/
     +20X,              '(MM)              (% DRY WEIGHT)'//)
C
      DR=(1.-F)*DZ
      DWC(M)=91.74*H(M)/((1.-POR)*DR*2.7)
      ZA(1)=Z+X-DY(1)/2.
C
          DO 1502 I=2,M
 1502     ZA(I)=ZA(I-1)-DY(I)
C                  ... UNFROZEN SOIL LENGTHS AND WATER CONTENT INCREASE
      WRITE(7,601) (ZA(I),DWC(I),I=1,M)
  601 FORMAT(18X,F10.2,10X,F10.2)
   32 STOP
      END
C
C
C
C     ***************************************************************
C     **                                                            **
         SUBROUTINE OUTPUT(HR,TC,Z,X,RC,P,SP,GRADT,V,TVOL,HINT,HT,W)
C     **                                                            **
C     ***************************************************************
C
      WRITE(6,151) HR,TC,Z,X,RC,P,SP,GRADT,V,TVOL,HINT,HT,W
  151 FORMAT(1F8.2,1F8.2,2F8.2,F8.4,F8.2,2X,1PE8.2,0PF8.4,1PE10.2,
     + 0P3F8.3,F8.4)
      RETURN
      END
C
C
C
C     ***************************************************************
C     **                                                            **
                    SUBROUTINE GAUSEL(A,B,C,D,N)
C     **                                                            **
C     ***************************************************************
C
      REAL A(1),B(1),C(1),D(1)
C
      IF(N.GT.1) GO TO 3
      C(N)=D(N)/A(N)
      GO TO 2
C
    3     DO 1 I=2,N
          A(I)=A(I)-B(I-1)*C(I)/A(I-1)
          D(I)=D(I)-D(I-1)*C(I)/A(I-1)
    1     C(I)=0.
      C(N+1)=0
      I=N
    4 C(I)=(D(I)-B(I)*C(I+1))/A(I)
      IF(I.LE.1) GO TO 2
    5 I=I-1
      GO TO 4
C
    2 RETURN
      END
C     ***************************************************************
C     **                                                            **
           SUBROUTINE SURF(P00,P01,P05,P1,P2,P5,P10,P,SP,RC,XX,XS,PEI)
C     **                                                            **
C     **        THIS SUBROUTINE GIVES THE FUNCTIONAL RELATIONSHIP      **
C     **   BETWEEN SP, PU, AND THE RATE OF COOLING OF THE FRINGE       **
C     **   FOR DEVON SILT WITH PE=0                                    **
C     **                                                            **
C     ***************************************************************
C
      IF(P.LT.5.1) GO TO 302
      SP=0.
      GO TO 300
  302 IF(P.LT.2.) GO TO 532
      P00=(5.-P)*2.2/5.
      P01=(6.-P)*3./6.
      GO TO 534
C
  532 P00=(6.-P)*2.2/6.+.75*(2.-P)**2.
      P01=(6.-P)*3./6.+1.2*(2.-P)**1.735
  534 P2=5.52-0.35*P + .1075*P**2. - 0.0305*P**3. + 0.00125*P**4.
C     P5=3.75+.0784*P - .118*P**2. + .03105*P**3. - .003087*P**4.
      P10=3.18+.0722*P - .05868*P**2. + .015687*P**3.-.0017241*P**4.
C
      IF(P.LT.6.) GO TO 520
      P1=(8.-P)*2.2/2.
      P05=(8.-P)*1.7/2.
      GO TO 304
  520 IF(P.LT.1.5) GO TO 521
      P1=2.2+(6.-P)*7.3/4.5
      P05=1.7+(6.-P)*5.2/4.5
      GO TO 304
C
  521 P1=(7.35-P)*10.5/7.35-(0.5*(1.5-P)**1.7)
      P05=(7.35-P)*10./7.35-(0.4*(1.5-P)**1.4)
C
  304 IF(RC.LT.2.5) GO TO 400
      SP=0.
      GO TO 300
  400 IF(RC.LT.1.) GO TO 410
      SP=2.E-04*(2.5-RC)*P10/1.5
      GO TO 300
  410 IF(RC.LT.0.5) GO TO 414
      SP=2.E-04*(P10+((1.-RC)*(P5-P10)/0.5))
      GO TO 300
  414 IF(RC.LT.0.2) GO TO 415
      SP=2.E-04*(P5+((0.5-RC)*(P2-P5)/0.3))
      GO TO 300
  415 IF(RC.LT.0.1) GO TO 418
      SP=2.E-04*(P2+((0.2-RC)*(P1-P2)/0.1))
      GO TO 300
  418 IF(RC.LT.0.05) GO TO 420
      SP=2.E-04*(P05+((RC-0.05)*(P1-P05)/0.05))
      GO TO 300
  420 IF(RC.LT.0.01) GO TO 422
      SP=2.E-04*(P01+((RC-0.01)*(P05-P01)/0.04))
      GO TO 300
  422 SP=2.E-04*(P00+(RC*(P01-P00)/0.01))
  300 SP=XX*SP

C ....................PRESSURE DEPENDENT SP.............................
      PE=(XS*.020/1000)+ PE)
      SP=SP*(EXP(-8.85*PE))
C ......................................................................
      CONTINUE
      RETURN
      END
```

INPUT FOR THE ONE DIMENSIONAL MODEL

```
1          2  200     1020.0           0
2     -1.0 4.0        .488       .460       .314      .48800     .65600
3          5000.         1.      .450       0.90      4400.0
4          5000.     1.E-05    1.E-03     0.75
5        -15.1
6            0.5
7            0.0      -0.30       2.5       .488         .830         1.0
8            1.0       50.0       0.0
```

OUTPUT FROM THE ONE DIMENSIONAL MODEL

```
        SILTY SOIL SPo=150 WATER AT SURFACE
    INITIAL UNFROZEN LENGTH IS:                   5000.0000 MM
    SATURATED LENGTH IS:                          5000.0000 MM
    POROSITY IS :                                    0.4500
    DEGREE OF SATURATION IN UNSAT. SOIL :            0.7500
    PHASE CHANGE FOR :                               0.9000 OF INITIAL WC
    FROZEN THERMAL CONDUCTIVITY IS :                 0.4880 MILLICAL/C/MM/S
    FROZEN FRINGE THERMAL CONDUCTIVITY IS :          0.4600 MILLICAL/C/MM/S
    UNFROZEN THERMAL CONDUCTIVITY IS :               0.3140 MILLICAL/C/MM/S
    UNSATURATED PERMEABILITY IS :                 1.0000E-05 MM/S
    SATURATED PERMEABILITY IS :                   1.0000E-03 MM/S
    NUMBER OF SEGMENTS :                                200
    COLD SIDE TEMPERATURE :                         -1.0000 CELCIUS
    SINUSOIDAL TEMP. TCMAX :                       -15.1000 CELCIUS
    WARM SIDE TEMPERATURE :                          4.0000 CELCIUS
    WATER TABLE IS :                                50.0000MM BELOW THE SURFACE
    FACTOR OF SP-PU-RC SURFACE IS :                  1.0000

    THE TIME STEP IS :                              1020.00 SECONDS
    THE NODE SEPARATION IS :                        25.0000 MM

TIME     TC   UNFROZEN FROZEN COOLING SUCTION     SP      GRAD T   INFLOW    TOTAL    INTAKE    TOTAL   POWER
              LENGTH   LENGTH  RATE             (MM**2)            VELOCITY  VOLUME   HEAVE     HEAVE

 (HR)   (C)    (MM)     (MM)   (C/HR)  (M H2O)  ( S*C )   (C/MM)    (MM/S)    (ML)     (MM)      (MM)   (MILLI-W)
0.0    -1.00 5000.00    0.0   3.0000    0.0    0.0        0.0      0.0        0.0     0.0       0.0    0.0
0.57   -1.00 4991.61    8.66  3.0000    0.0    0.0        0.3101   0.0        0.0     0.0       0.263  0.5150
1.13   -1.00 4989.69   10.73  0.3855    0.00   5.06E-04   0.1064   5.35E-05   0.006   0.060     0.422  0.1327
1.70   -1.00 4988.46   12.28  0.1922    0.00   1.36E-03   0.0919   1.25E-04   0.031   0.343     0.720  0.1154
2.27   -1.00 4987.57   13.51  0.1205    0.01   1.64E-03   0.0822   1.51E-04   0.061   0.666     1.076  0.1052
2.55   -1.00 4987.18   14.07  0.1005    0.01   1.87E-03   0.0785   1.55E-04   0.077   0.841     1.264  0.1015
3.12   -1.00 4986.45   15.16  0.0830    0.01   1.94E-03   0.0725   1.40E-04   0.105   1.160     1.610  0.0946
3.68   -1.00 4985.75   16.16  0.0742    0.00   1.92E-03   0.0677   1.29E-04   0.133   1.454     1.930  0.0893
4.25   -1.00 4985.07   17.16  0.0668    0.00   1.90E-03   0.0636   1.21E-04   0.156   1.727     2.227  0.0842
4.53   -1.00 4984.74   17.63  0.0635    0.00   1.89E-03   0.0618   1.17E-04   0.170   1.857     2.388  0.0820
5.10   -1.00 4984.10   18.54  0.0578    0.00   1.88E-03   0.0586   1.10E-04   0.193   2.105     2.640  0.0780
5.67   -1.00 4983.48   19.41  0.0530    0.00   1.88E-03   0.0559   1.04E-04   0.215   2.340     2.897  0.0748
6.23   -1.00 4982.90   20.24  0.0488    0.00   1.86E-03   0.0535   9.88E-05   0.235   2.562     3.141  0.0715
6.52   -1.00 4982.61   20.65  0.0471    0.00   1.84E-03   0.0524   9.63E-05   0.245   2.668     3.259  0.0700
7.08   -1.00 4982.04   21.44  0.0441    0.00   1.82E-03   0.0504   9.16E-05   0.264   2.876     3.485  0.0674
7.65   -1.00 4981.48   22.21  0.0414    0.00   1.80E-03   0.0486   8.74E-05   0.282   3.073     3.702  0.0651
8.22   -1.00 4980.95   22.95  0.0390    0.00   1.78E-03   0.0470   8.36E-05   0.299   3.261     3.910  0.0629
8.50   -1.00 4980.70   23.31  0.0378    0.00   1.78E-03   0.0462   8.21E-05   0.306   3.352     4.011  0.0619
9.07   -1.00 4980.18   24.03  0.0358    0.00   1.76E-03   0.0448   7.90E-05   0.324   3.529     4.207  0.0601
9.63   -1.00 4979.67   24.72  0.0340    0.00   1.75E-03   0.0435   7.63E-05   0.339   3.700     4.398  0.0584
10.20  -1.00 4979.18   25.40  0.0322    0.00   1.74E-03   0.0423   7.36E-05   0.355   3.865     4.578  0.0566
15.02  -1.00 4975.36   30.56  0.0227    0.00   1.68E-03   0.0260   5.67E-05   0.467   5.093     5.925  0.0470
20.12  -1.00 4971.40   35.55  0.0195    0.00   1.66E-03   0.0224   3.87E-05   0.547   5.956     6.952  0.0403
25.22  -1.00 4967.67   39.93  0.0154    0.00   1.63E-03   0.0204   3.40E-05   0.613   6.680     7.602  0.0357
30.03  -1.00 4964.66   43.85  0.0129    0.00   1.61E-03   0.0191   3.06E-05   0.669   7.286     8.510  0.0326
35.13  -1.00 4961.93   47.28  0.0110    0.00   1.60E-03   0.0176   2.82E-05   0.723   7.876     9.213  0.0299
40.23  -1.00 4959.21   50.64  0.0098    0.00   1.56E-03   0.0165   2.60E-05   0.772   8.418     9.853  0.0279
45.05  -1.00 4956.77   53.64  0.0088    0.00   1.53E-03   0.0157   2.41E-05   0.816   8.889    10.412  0.0263
50.15  -1.00 4954.32   56.54  0.0077    0.00   1.50E-03   0.0149   2.24E-05   0.856   9.332    10.863  0.0249
55.25  -1.00 4951.97   59.51  0.0070    0.00   1.47E-03   0.0142   2.10E-05   0.896   9.766    11.480  0.0236
60.07  -1.00 4949.86   62.10  0.0065    0.00   1.46E-03   0.0137   1.98E-05   0.933  10.169    11.961  0.0227
```

65.17	-1.00	4947.67	64.73	0.0060	0.00	1.43E-03	0.0132	1.88E-05	0.986	10.585	12.408	0.0217
70.27	-1.00	4945.57	67.27	0.0056	0.00	1.41E-03	0.0127	1.79E-05	1.002	10.921	12.847	0.0209
75.00	-1.00	4942.88	69.59	0.0052	0.00	1.40E-03	0.0123	1.72E-05	1.033	11.262	13.246	0.0202
80.15	-1.00	4941.59	71.86	0.0049	0.00	1.38E-03	0.0119	1.65E-05	1.063	11.568	13.653	0.0195
85.00	-1.00	4939.48	74.13	0.0046	0.00	1.37E-03	0.0116	1.59E-05	1.091	11.883	14.027	0.0189
90.10	-1.00	4938.04	76.36	0.0044	0.00	1.36E-03	0.0113	1.53E-05	1.120	12.205	14.400	0.0183
95.20	-1.00	4936.22	78.53	0.0041	0.00	1.35E-03	0.0110	1.48E-05	1.147	12.505	14.758	0.0178
100.02	-1.00	4934.57	80.63	0.0039	0.00	1.34E-03	0.0107	1.44E-05	1.172	12.780	15.100	0.0174
105.12	-1.00	4932.88	82.68	0.0037	0.00	1.33E-03	0.0104	1.39E-05	1.196	13.063	15.445	0.0169
110.22	-1.00	4931.10	84.61	0.0036	0.00	1.32E-03	0.0102	1.35E-05	1.224	13.337	15.779	0.0165
160.08	-1.00	4918.38	102.30	0.0025	0.00	1.28E-03	0.0086	1.00E-05	1.440	15.604	18.604	0.0136
210.23	-1.00	4903.59	117.40	0.0018	0.00	1.25E-03	0.0074	9.30E-06	1.620	17.063	21.067	0.0118
260.10	-1.00	4893.38	130.81	0.0015	0.00	1.24E-03	0.0067	8.25E-06	1.777	18.272	23.107	0.0106
310.25	-1.00	4881.90	143.15	0.0013	0.00	1.23E-03	0.0061	7.48E-06	1.919	20.016	25.107	0.0097
360.12	-1.00	4872.48	154.30	0.0011	0.00	1.22E-03	0.0057	6.90E-06	2.046	22.320	26.647	0.0090
410.27	-1.00	4863.47	165.00	0.0009	0.00	1.21E-03	0.0053	6.43E-06	2.166	23.620	28.471	0.0084
460.13	-1.00	4855.21	174.77	0.0008	0.00	1.21E-03	0.0050	6.05E-06	2.280	24.848	29.984	0.0079
510.00	-1.00	4847.27	184.14	0.0008	0.00	1.20E-03	0.0048	5.72E-06	2.386	25.997	31.411	0.0075
560.15	-1.00	4839.88	193.11	0.0007	0.00	1.20E-03	0.0046	5.44E-06	2.486	27.094	32.775	0.0072
610.02	-1.00	4832.40	201.66	0.0006	0.00	1.20E-03	0.0044	5.20E-06	2.581	28.134	34.067	0.0068
660.17	-1.00	4825.40	209.82	0.0006	0.00	1.19E-03	0.0042	4.98E-06	2.673	29.135	35.313	0.0066
710.03	-1.00	4818.61	217.69	0.0005	0.00	1.19E-03	0.0040	4.80E-06	2.761	30.091	36.503	0.0063
760.18	-1.00	4812.21	225.44	0.0005	0.00	1.19E-03	0.0039	4.63E-06	2.846	31.016	37.655	0.0061
810.05	-1.00	4806.03	232.73	0.0005	0.00	1.19E-03	0.0038	4.48E-06	2.926	31.906	38.763	0.0059
860.20	-1.00	4799.80	240.04	0.0004	0.00	1.18E-03	0.0037	4.34E-06	3.007	32.772	39.842	0.0057
910.07	-1.00	4793.63	247.26	0.0004	0.00	1.18E-03	0.0036	4.20E-06	3.084	33.606	40.881	0.0056
960.22	-1.00	4788.08	253.80	0.0004	0.00	1.18E-03	0.0035	4.08E-06	3.158	34.420	41.895	0.0054
1010.08	-1.00	4782.59	260.28	0.0004	0.00	1.18E-03	0.0034	3.98E-06	3.231	35.209	42.880	0.0053
1060.23	-1.00	4777.08	266.79	0.0004	0.00	1.18E-03	0.0033	3.88E-06	3.302	35.982	43.844	0.0052
1110.10	-1.00	4771.56	273.22	0.0003	0.00	1.18E-03	0.0032	3.78E-06	3.370	36.732	44.779	0.0050
1160.25	-1.00	4766.02	279.57	0.0003	0.00	1.18E-03	0.0031	3.70E-06	3.436	37.467	45.696	0.0049
1210.12	-1.00	4760.88	285.63	0.0003	0.00	1.18E-03	0.0031	3.62E-06	3.504	38.182	46.587	0.0048
1260.27	-1.00	4756.12	291.36	0.0003	0.00	1.17E-03	0.0030	3.55E-06	3.568	38.885	47.465	0.0047
1310.13	-1.00	4751.30	297.02	0.0003	0.00	1.17E-03	0.0030	3.48E-06	3.631	39.571	48.321	0.0046
1360.00	-1.00	4746.48	302.66	0.0003	0.00	1.17E-03	0.0029	3.41E-06	3.693	40.243	49.160	0.0045
1410.15	-1.00	4741.85	308.33	0.0003	0.00	1.17E-03	0.0029	3.34E-06	3.754	40.905	49.986	0.0045
1460.02	-1.00	4736.64	313.85	0.0003	0.00	1.17E-03	0.0028	3.28E-06	3.813	41.553	50.795	0.0044
1510.17	-1.00	4732.00	319.50	0.0003	0.00	1.17E-03	0.0028	3.22E-06	3.872	42.191	51.592	0.0043
1560.03	-1.00	4727.18	325.16	0.0002	0.00	1.17E-03	0.0027	3.16E-06	3.929	42.814	52.370	0.0042
1610.18	-1.00	4722.70	330.44	0.0002	0.00	1.17E-03	0.0027	3.11E-06	3.985	43.430	53.139	0.0042
1660.05	-1.00	4718.57	335.32	0.0002	0.00	1.17E-03	0.0026	3.07E-06	4.041	44.033	53.892	0.0041
1710.20	-1.00	4714.42	340.21	0.0002	0.00	1.17E-03	0.0026	3.02E-06	4.095	44.631	54.639	0.0040
1760.07	-1.00	4710.30	345.07	0.0002	0.00	1.17E-03	0.0026	2.98E-06	4.149	45.216	55.370	0.0040
1810.22	-1.00	4706.15	349.95	0.0002	0.00	1.17E-03	0.0025	2.93E-06	4.203	45.796	56.095	0.0039
1860.08	-1.00	4702.02	354.76	0.0002	0.00	1.16E-03	0.0025	2.88E-06	4.255	46.365	56.808	0.0039
1910.23	-1.00	4697.88	359.63	0.0002	0.00	1.16E-03	0.0024	2.85E-06	4.307	46.926	57.510	0.0038
1960.10	-1.00	4693.75	364.45	0.0002	0.00	1.16E-03	0.0024	2.81E-06	4.357	47.481	58.201	0.0038
2010.25	-1.00	4689.60	369.26	0.0002	0.00	1.16E-03	0.0024	2.77E-06	4.408	48.029	58.885	0.0037
2060.12	-1.00	4685.48	374.06	0.0002	0.00	1.16E-03	0.0024	2.74E-06	4.457	48.567	59.558	0.0037
2110.27	-1.00	4681.33	378.85	0.0002	0.00	1.16E-03	0.0023	2.70E-06	4.506	49.101	60.225	0.0036
2160.13	-1.00	4677.20	383.68	0.0002	0.00	1.16E-03	0.0023	2.67E-06	4.554	49.624	60.879	0.0036
2210.00	-1.00	4673.08	388.44	0.0002	0.00	1.16E-03	0.0023	2.63E-06	4.602	50.141	61.525	0.0035
2260.15	-1.00	4669.12	393.06	0.0002	0.00	1.16E-03	0.0022	2.60E-06	4.649	50.654	62.159	0.0035
2310.02	-1.00	4665.86	397.12	0.0002	0.00	1.16E-03	0.0022	2.57E-06	4.695	51.159	62.787	0.0034
2360.17	-1.00	4662.22	401.20	0.0002	0.00	1.16E-03	0.0022	2.55E-06	4.741	51.662	63.425	0.0034
2410.03	-1.00	4658.78	405.26	0.0002	0.00	1.16E-03	0.0022	2.52E-06	4.787	52.158	64.043	0.0034
2460.18	-1.00	4655.33	409.33	0.0002	0.00	1.16E-03	0.0022	2.49E-06	4.832	52.648	64.656	0.0033
2510.05	-1.00	4651.89	413.37	0.0002	0.00	1.16E-03	0.0021	2.47E-06	4.876	53.132	65.253	0.0033

2560.20	-1.00	4648.43	417.43	0.0001	0.00	1.16E-03	0.0021	2.44E-06	4.920	53.614	65.865	0.0033
2610.07	-1.00	4645.00	421.46	0.0001	0.00	1.16E-03	0.0021	2.42E-06	4.964	54.088	66.459	0.0032
2660.22	-1.00	4641.54	425.51	0.0001	0.00	1.16E-03	0.0021	2.40E-06	5.007	54.560	67.050	0.0032
2710.08	-1.00	4638.10	429.53	0.0001	0.00	1.16E-03	0.0021	2.37E-06	5.050	55.025	67.631	0.0032
2760.23	-1.00	4634.64	433.56	0.0001	0.00	1.15E-03	0.0020	2.35E-06	5.093	55.488	68.210	0.0031
2810.10	-1.00	4631.21	437.57	0.0001	0.00	1.15E-03	0.0020	2.33E-06	5.134	55.944	68.780	0.0031
2860.25	-1.00	4627.75	441.58	0.0001	0.00	1.15E-03	0.0020	2.30E-06	5.176	56.398	69.346	0.0031
2910.12	-1.00	4624.31	445.59	0.0001	0.00	1.15E-03	0.0020	2.28E-06	5.217	56.846	69.907	0.0031
2960.27	-1.00	4620.88	449.61	0.0001	0.00	1.15E-03	0.0020	2.26E-06	5.258	57.292	70.464	0.0030
3010.13	-1.00	4617.42	453.59	0.0001	0.00	1.15E-03	0.0019	2.24E-06	5.299	57.721	71.012	0.0030
3060.00	-1.00	4613.96	457.57	0.0001	0.00	1.15E-03	0.0019	2.22E-06	5.336	58.166	71.555	0.0030
3110.15	-1.00	4610.52	461.57	0.0001	0.00	1.15E-03	0.0019	2.20E-06	5.376	58.598	72.097	0.0029
3160.02	-1.00	4607.08	465.54	0.0001	0.00	1.15E-03	0.0019	2.18E-06	5.417	59.026	72.630	0.0029
3210.17	-1.00	4603.63	469.53	0.0001	0.00	1.15E-03	0.0018	2.16E-06	5.457	59.452	73.161	0.0029
3260.03	-1.00	4600.18	473.49	0.0001	0.00	1.15E-03	0.0018	2.14E-06	5.495	59.872	73.685	0.0028
3310.18	-1.00	4596.73	477.47	0.0001	0.00	1.15E-03	0.0018	2.12E-06	5.534	60.290	74.207	0.0028
3360.05	-1.00	4593.66	481.17	0.0001	0.00	1.15E-03	0.0018	2.11E-06	5.571	60.702	74.721	0.0028
3410.20	-1.00	4590.78	484.45	0.0001	0.00	1.15E-03	0.0018	2.09E-06	5.609	61.114	75.235	0.0028
3460.07	-1.00	4588.04	487.70	0.0001	0.00	1.15E-03	0.0018	2.08E-06	5.647	61.520	75.742	0.0028
3510.22	-1.00	4585.27	490.96	0.0001	0.00	1.15E-03	0.0018	2.06E-06	5.684	61.926	76.246	0.0027
3560.08	-1.00	4582.52	494.23	0.0001	0.00	1.15E-03	0.0018	2.05E-06	5.721	62.327	76.746	0.0027
3610.23	-1.00	4579.75	497.48	0.0001	0.00	1.15E-03	0.0018	2.03E-06	5.757	62.726	77.247	0.0027
3660.10	-1.00	4577.00	500.73	0.0001	0.00	1.15E-03	0.0018	2.02E-06	5.794	63.123	77.740	0.0027
3710.25	-1.00	4574.24	503.98	0.0001	0.00	1.14E-03	0.0018	2.01E-06	5.830	63.516	78.233	0.0027
3760.12	-1.00	4571.48	507.23	0.0001	0.00	1.14E-03	0.0017	1.99E-06	5.866	63.906	78.718	0.0026
3810.27	-1.00	4568.73	510.46	0.0001	0.00	1.14E-03	0.0017	1.98E-06	5.902	64.297	79.204	0.0026
3860.13	-1.00	4565.97	513.71	0.0001	0.00	1.14E-03	0.0017	1.97E-06	5.937	64.682	79.684	0.0026
3910.00	-1.00	4563.22	516.93	0.0001	0.00	1.14E-03	0.0017	1.95E-06	5.972	65.064	80.160	0.0026
3960.15	-1.00	4560.46	520.16	0.0001	0.00	1.14E-03	0.0017	1.94E-06	6.007	65.446	80.636	0.0026
4010.02	-1.00	4557.71	523.39	0.0001	0.00	1.14E-03	0.0017	1.93E-06	6.042	65.823	81.105	0.0025
4060.17	-1.00	4554.96	526.62	0.0001	0.00	1.14E-03	0.0017	1.92E-06	6.076	66.200	81.574	0.0025
4110.03	-1.00	4552.19	529.86	0.0001	0.00	1.14E-03	0.0017	1.90E-06	6.110	66.572	82.037	0.0025
4160.18	-1.00	4549.43	533.07	0.0001	0.00	1.14E-03	0.0017	1.89E-06	6.145	66.946	82.500	0.0025
4210.05	-1.00	4546.68	536.28	0.0001	0.00	1.14E-03	0.0016	1.88E-06	6.178	67.312	82.957	0.0025
4260.20	-1.00	4543.91	539.50	0.0001	0.00	1.14E-03	0.0016	1.87E-06	6.212	67.679	83.414	0.0024
4310.07	-1.00	4541.16	542.70	0.0001	0.00	1.14E-03	0.0016	1.85E-06	6.245	68.042	83.865	0.0024
4360.21	-1.00	4538.38	545.92	0.0001	0.00	1.14E-03	0.0016	1.84E-06	6.278	68.404	84.315	0.0024
4400.16	-1.00	4536.19	548.48	0.0001	0.00	1.14E-03	0.0016	1.83E-06	6.308	68.681	84.672	0.0024

APPENDIX C.

Two Dimensionsl Model - Program, Input and Output.

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C*************************************************************
C  THIS PROGRAM IS PREPARED FOR THE PREDICTION OF TEMPERATURE
C  DISTRIBUTION IN AN ARBITRARY MEDIA UNDER VARIOUS INITIAL
C AND BOUNDARY CONDITIONS -- TWO DIMENSION SYMMETRICAL CASE
C  AS TYPED IN  NOV.  5/84
C *****************************************************************
      DIMENSION TB(100), TBL(100), CORR(12)
      COMMON /BLOCK/I,J,K,M,DT,D,NWS,DTK1,DF
      COMMON /BLK1/T(12,12,30),ID(180),NTYPE(12,12),N(12)
      COMMON /BLK2/DEN(12,12),WC(12,12),SPHT(12,12),COND(12,12)
      COMMON /BLK3/C1(12,12),C2(12,12),C3(12,12),C4(12,12)
      COMMON /BLK4/C5(12,12),C6(12,12),C7(12,12),ICE(12,12)
      COMMON /BLK5/X(12,12),Z(12,12),DTTMIN(12,12)
      COMMON /BLK6/TBB(12,100),TBBL(12,100)
      COMMON /BLK7/INIT,TINIT,TIB(12)
      COMMON /BLK8/IBOND,BOND,ABOND,BBOND,CBOND,DBOND,HALFT,NSTEP,TBUILD
      COMMON /BLK10/STEPA(365),STEPB(365),STEPT(365)
      COMMON /BLK9/LBOND,BONDL
      DATA TFREZ/32.0/,CELL/30.0/,JMAX,IMAX/12,12/
C **************************************************************
C**   SOIL PROFILE AND ITS PROPERTIES (TWO DIMENSIONAL
C**   ANALYSIS) SUBSCRIPTS (I,J) AND K DENOTING SPACE AND
C**          TIME STEPS RESPECTIVELY,   I,J,K=1,2,3 ....
C**   READ(5,9) ID
C     MN=TOTAL NUMBER OF CELLS
C     M=TOTAL NUMBER OF LAYERS
C     N(J)=NUMBER OF CELLS FOR LAYER J
C     INITIALIZE THE HEAVE PROGRAM
      HVT=0
      READ(5,10) MN,M, (N(J), J=1,M)
      NN=N(M)
C    Z(THICKNESS) AND X(WIDTH) IN INCHES
C    DEN(DRY DENSITY) IN PCF
C     WC(WATER CONTENT) IN PERCENT
      DO 101 J=1,JMAX
      DO 101 I=1,IMAX
 101  X(I,J)=0.0
      DO 110 IJ=1,MN
 110  READ(5,11) J,I,NTYPE(I,J),Z(I,J),X(I,J),DEN(I,J),WC(I,J)
      IN=1
      CALL OUT(IN)
      DO 113 J=1,M
      II=1
 111  IF(X(II,J).GE.0.01) GO TO 112
      II=II+1
      GO TO 111
 112  NJ=N(J)+II-1
      DO 113 I =II,NJ
      Z(I,J)=Z(I,J)/12.0
 113  X(I,J)=X(I,J)/12.0
C *****************************************************************
C    READ VOLUMETRIC HEAT AND THERMAL CONDUCTIVITY OF ALL
C    CELLS WHICH ARE ASSUMED, VARIES LINEARLY WITH TEMPERATURE
C    I.E. VOLUMETRIC HEAT = C1*(TEMP)+C2
C         CONDUCTIVITY =C3*(TEMP) +C4
C    WHERE C1,C2,C3 AND C4 ARE CONSTANTS
C ****************************************************************
C      VOLUMETRIC HEAT IN BTU/CU*T/F
C    THERMAL CONDUCTIVITY IN BTU/FT/HOUR/F
 120  DO 121 IJ=1,MN
 121  READ(5,16) J,I,C1(I,J),C2(I,J),C3(I,J),C4(I,J)
      IN=2
      CALL OUT(IN)
C******************************************************************
C**   ICE FORMATION CHARACTERISTICS
C**   ASSUME THAT FOR EACH CELL, THE PERCENT MOISTURE FROZEN IS
C**   AN EXPONENTIAL FUNCTION OF TEMPERATURE.
C**    PERCENT MOISTURE FROZEN = C5-EXP(C6*TEMP-C7)
C**   WHERE C5,C6 AND C7 ARE CONSTANTS
C**   READ 1  FOR UNKNOWN COEFFICIENTS (C5,C6,C7)
C**   READ 2 FOR  DATA TO BE FITTING INTO AN EXPONENTIAL FUNCTION
C**   READ 3 FOR DRY CELL
C******************************************************************
 130  DO 134 IJ=1,MN
      READ(5,11) J, I, ICE(I,J)
      ICEN=ICE(I,J)
      GO TO (131,132,133), ICEN
 131  READ(5,12) C5(I,J), C6(I,J), C7(I,J)
      GO TO 134
 132  CALL CURVE(C55,C66,C77)
      C5(I,J)=C55
      C6(I,J)=C66
      C7(I,J)=C77
      GO TO 134
 133  C5(I,J)=1.0
      C6(I,J)=0.0
      C7(I,J)=0.0
 134  CONTINUE
      IN=3
      CALL OUT(IN)
C**************************************************************
C   INITIAL CONDITION T(I,J,1), I, J=1,2, ..
C**   READ 1 FOR CONSTANT TEMPERATURE
C**   READ 2 FOR KNOWN TEMPERATURES AT CENTRE OF ALL CELLS
```

```
C*****************************************************************
200   READ(5,11) INIT
      IN=4
      GO TO (210,220), INIT
C-----------------------------------------------------------------
C   T(I,J,1)=CONSTANT FOR ALL CELLS
C-----------------------------------------------------------------
210   READ(5,12) TINIT
      DO 213 J=1,M
      II=1
211   IF(X(II,J).GE.0.1) GO TO 212
      II=II+1
      GO TO 211
212   NJ=N(J)+II-1
      DO 213 I=II,NJ
213   T(I,J,1)=TINIT
      DO 214 I=1,NM
      TIB(I)=TINIT
214   TBBL(I,1)=TINIT
      CALL OUT(IN)
      GO TO 300
C---------------------------------------------------------------
C     TEMPERATURES AT CENTERS OF ALL CELLS GIVEN
C     T(I,J,1) -- TEMPERATURE  FOR CELL(I,J)
C     TIB(I) -- TEMPERTURE AT UPPER BOUNDARY
C     TBBL(I,1) -- TEMPERATURE AT LOWER BOUNDARY
C---------------------------------------------------------------
220    DO 223 J=1,M
       II=1
221    IF(X(II,J).GE.0.1) GO TO 222
       II=II+1
       GO TO 221
222    NJ=N(J)+II-1
223    READ(5,14) (T(I,J,1), I=II,NJ)
       READ(5,14) (TIB(I), I=1,NM)
       READ(5,14) (TBBL(I,1), I=1,NM)
       CALL OUT(IN)
C*****************************************************************
C**    TIME INCREMENT, DURATION OF FREEZING PERIOD
C**    THOUR - TOTAL PERIOD IN HOURS TO BE ANALYZED
C**    DT - TIME INCREMENT IN HOURS
C**    DTOUT - OUTPUT TIME INTERVAL IN HOURS
C**    TOTAL - TOTAL TIME HAVE BEEN COMPUTED
C**    NDT - NUMBER OF CELL REQUIRE SMALLER DT
C**    JT,IT,DTTM - LOCATION AND TIME INCREMENT FOR CELL MENTIONED
C*******************************************************************
300    READ(5,13) THOUR,DT,DTOUT,TOTAL,DF,NWS
       WRITE(6,301) NWS,DF
301    FORMAT(///2X,42HDEPTH TO WATER SOURCE, ELEMENT NUMBER THAT,
      122H HEAVE BEGINS AT IS   ,I15,/2X,19HDEPTH TO FOOTING IS,1F8.2)
       WRITE(6,302) DT
302    FORMAT(/////2X,23HINCREMENT OF TIME, DT =, F7.3,7H HOURS,1X,
      1 47H(EXCEPT FOR THOSE CELLS LISTED FOLLOWS, IF ANY))
       DO 321 J=1,M
       II=1
310    IF(X(II,J).GE.0.1) GO TO 320
       II=II+1
       GO TO 310
320    NJ=N(J)+II-1
       DO 321 I=II,NJ
321    DTTMIN(I,J)=DT
       READ(5,11) NDT
       IF(NDT.EQ.0) GO TO 340
       WRITE(6,322)
322    FORMAT(/6X,1HJ,3X,1HI,4X,2HDT)
       DO 330 IJ=1,NDT
       READ(5,15) JT,IT,DTTM
       DTTMIN(IT,JT)=DTTM
330    WRITE(6,331) JT,IT,DTTM
331    FORMAT(3X,2I4,F8.3)
340    CALL HOUR(DT,CELL,THOUR,TOTAL,LTIME,TIME)
       LTIME=LTIME
       KT=TIME/DT+1.0
       KTK=KT-1
C ********************************************************************
C**    BOUNDARY CONDITIONS, T(I,0,K) OF TB(K), K=1,2..
C**    READ 1 FOR CONSTANT
C**    READ 2 FOR ALGEBRAIC FUNCTION
C**    READ 3 FOR TRIGONOMETRIC FUNCTION
C**    READ 4 FOR STEP FUNCTION
C*********************************************************************
400    READ(5,11) IBOND
       IN=6
       GO TO(410,420,430,440,450), IBOND
C-----------------------------------------------------------------
C       T(0,TIME)=CONSTANT FOR ALL THE TIME
C-----------------------------------------------------------------
410    READ(5,12) BOND
       DO 411 K=1,KT
411    TB(K)=BOND
       CALL OUT(IN)
       GO TO 500
C-----------------------------------------------------------------
C      T(0,TIME)=A+B*TIME+C*TIME**2+D*TIME**3
```

```
      C-----------------------------------------------------------------
      420   READ(5,15) ABOND,BBOND,CBOND,DBOND,UNIT,START
            DDT=START
            TOTAL=START
            DO 421 K=1,KT
            TB(K)=ABOND+BBOND*DDT/UNIT+CBOND*(DDT/UNIT)**2+DBOND*
           1 (DDT/UNIT)**3
      421   DDT=DDT+DT
            CALL OUT(IN)
            GO TO 500
      C-----------------------------------------------------------------
      C     T(0,TIME)=A*SIN(PI*KT/T) + B*COS(PI*KT/T),
      C       WHERE T IS ONE HALF PERIOD IN TIME SCALE
      C        KT  IS THE TIME AT INTERVAL K
      C-----------------------------------------------------------------
      430   READ(5,15) ABOND,BBOND,UNIT,START,HALFT
            DDT=START
            TOTAL=START
            DO 431 K=1,KT
            TPI=3.14159*(DDT/UNIT)/HALFT
            TB(K)=32-(ABOND*SIN(TPI)+BBOND*COS(TPI))
      431   DDT=DDT+DT
            CALL OUT(IN)
            GO TO 500
      C------------------------------------------------------------------
      C     STEP BOUNDARY -- T(0,TIME)=A, T=T0 TO T=T1, T(0,TIME)=P,
      C       T=T1 TO T=T2. ..... T(0,TIME)=N,T=T(N-1) TO T=TN
      C------------------------------------------------------------------
      440   READ(5,11) NSTEP
            READ(5,12) (STEPA(I),STEPB(I),STEPT(I), I=1,NSTEP)
            READ(5,12) UNIT, START
            DO 441 I=1,NSTEP
            STEPA(I)=STEPA(I)*UNIT
      441   STEPB(I)=STEPB(I)*UNIT
            CALL OUT(IN)
            DDT=START
            TOTAL=START
            I=1
            DO 444 K=1,KT
      442   IF(DDT.GE.STEPA(I).AND.DDT.LT.STEPB(I)) GO TO 443
            I=I+1
            GO TO 442
      443   TB(K)=STEPT(I)
      444   DDT=DDT+DT
            GO TO 500
      450   READ(5,15) ABOND,BBOND,UNIT,START,HALFT
            READ(5,16) NHEAT, TBUILD
            DDT=START
            TOTAL=START
            DO 451 K=1,KT
            TPI=3.14159*(DDT/UNIT)/HALFT
            TB(K)= 32.0-(ABOND*SIN(TPI))
      451   DDT=DDT+DT
            CALL OUT(IN)
      C*****************************************************************
      C**      CORRECTION BOUNDARY VALUES FOR AIR-GROUND INTERFACE
      C*****************************************************************
      500   READ(5,14) (CORR(I),.I=1,NM)
            DO 510 K=1,KT
            DO 510 I=1,NM
            IF(TB(K).LE.32.0) TBB(I,K)=32.0-(32.0-TB(K))*CORR(I)
      510   IF(TB(K).GT.32.0) TBB(I,K)=32.0+(TB(K)-32.0)*(2.0-CORR(I))
            WRITE(6,511) NM, (CORR(I), I=1,NM)
      511   FORMAT(/ 1X,37HCORRECTION FACTOR FOR BOUNDARY VALUES,
           1 28H FOR AIR GROUND INTERFACE =,2X,7H(I=1,.,I2,1H)/14F6.2)
            IF (IBOND.NE.5) GO TO 600
            DO 512 K=1,KT
            DO 512 I=1,NHEAT
      512   TBB(I,K)=TBUILD
      C****************************************************************
      C**   SPECIFY LOWER BOUNDARY CONDITION
      C**      READ 1 FOR CONSTANT
      C**      READ 2 FOR PERFECT INSULATION
      C**      READ 3 FOR TEMPERATURE SAME AS BOUNDARY LAYER
      C**      READ 4 FOR SPECIFIED TEMPERATURE
      C****************************************************************
      600   READ(5,11) LBOND
            IN=2
            GO TO(610,620,630,640), LBOND
      610   CALL OUT(IN)
            GO TO 700
      620   CALL OUT(IN)
            GO TO 700
      630   CALL OUT(IN)
            GO TO 700
      640   READ(5,12) BONDL
            CALL OUT(IN)
      C*******************************************************************
      C**  CALCULATING TEMPERATURES AT VARIES CELLS
      C*******************************************************************
      700   DO 999 LLL=1,LTIME
            IF(LLL.EQ.1.AND.TOTAL.EQ.0.0) GO TO 730
            IF(LLL.EQ.1) GO TO 705
            DO 702 J=1,M
            II=1
      701   IF(X(II,J).GE.0.1) GO TO 702
            II=II+1
      GO TO 701
702   NJ=N(J)+II-1
      DO 703 I=II,NJ
703   T(I,J,1)=T(I,J,KT)
      DO 704 I=1,NM
      TBB(I,1)=TBB(I,KT)
704   TBBL(I,1)=TBBL(I,KT)
      TBL(1)=TBL(KTK)
      REMAIN=THOUR-TOTAL
      IF(REMAIN.GT.TIME) GO TO 705
      TIME=REMAIN
      KT=TIME/DT+1.0
      KTK=KT-1
705   DDT=TOTAL
      GO TO(706,708,710,712,1713), IBOND
706   DO 707 K=1,KT
707   TB(K)=ABOND
      GO TO 720
708   DO 709 K=1,KT
      TB(K)=ABOND+BBOND*DDT/UNIT+CBOND*(DDT/UNIT)**2+DBOND*
     1 (DDT/UNIT)**3
709   DDT=DDT+DT
      GO TO 720
710   DO 711 K=1,KT
      TPI=3.14159*(DDT/UNIT)/HALFT
      TB(K)=32-(ABOND*SIN(TPI)+BBOND*COS(TPI))
711   DDT=DDT+DT
      GO TO 720
1713  DO 1714 K=1,KT
      TPI=3.14159*(DDT/UNIT)/HALFT
      TB(K)=32-(ABOND*SIN(TPI)+BBOND*COS(TPI))
1714  DDT=DDT+DT
      GO TO 720
712   I=1
      IK=1
      DO 715 K=1,KT
713   IF(DDT.GE.STEPA(I).AND.DDT.LE.STEPB(I)) GO TO 714
      I=I+1
      GO TO 713
714   TB(K)=STEPT(I)
      IF(IK.EQ.1) IKK=1
      IK=IK+1
715   DDT=DDT+DT
720   DO 721 K=1,KT
      DO 721 I=1,NM
      IF(TB(K).LE.32.0) TBB(I,K)=32.0-(32.0-TB(K))*CORR(I)
721   IF(TB(K).GT.32.0) TBB(I,K)=32.0+(TB(K)-32.0)*(2.0-CORR(I))
      IF (IBOND.NE.5) GO TO 740
      DO 722 K=1,KT
      DO 722 I=1,NHEAT
722   TBB(I,K)=TBUILD
      GO TO 740
C------------------------------------------------------------------
C     TEMPERATURE IMMEDIATELY AFTER THE PROCESS STARTS IS TAKEN
C     TO BE THE AVERAGE OF INITIAL AND BOUNDARY CONDITIONS
C------------------------------------------------------------------
730    DO 731 I=1,NM
731    TBB(I,1)=(TIB(I)+TBB(I,1))/2.0
C-------------------------------------------------------------------
C    WRITE INITIAL TEMPERATURES
C------------------------------------------------------------------
740    DTK=TOTAL
       IF(LLL.NE.1) GO TO 741
       KK=0
       CALL OUTPUT(KK,NM,TOTAL,DTOUT,TB)
741    K=1
742    DO 755 J=1,M
       II=1
743    IF(X(II,J).GE.0.1) GO TO 744
       II=II+1
       GO TO 743
744    NJ=N(J)+II-1
       DO 755 I=II,NJ
       IF(WC(I,J).EQ.0.0) GO TO 745
       IF(T(I,J,K).GE.TFREZ) PARTF=0.0
       IF(T(I,J,K).LT.TFREZ) PARTF=(C5(I,J)-EXP(C6(I,J)*T(I,J,K)
     1   +C7(I,J)))/100.0
       GO TO 746
745    PARTF=0.0
746    PARTU=1.0-PARTF
C----------------------------------------------------------------
C    COMPUTE VOLUMETRIC HEAT
C----------------------------------------------------------------
750     SPHT(I,J)=VH(T(I,J,K),C1(I,J),C2(I,J),DEN(I,J),WC(I,J),PARTF,
      1   PARTU)
C-----------------------------------------------------------------
C    COMPUTE THERMAL CONDUCTIVITY
C-----------------------------------------------------------------
760     COND(I,J)=TC(T(I,J,K),C3(I,J),C4(I,J),DEN(I,J),WC(I,J),PARTF,
      1   PARTU)
C    CHECK STOP FOR NEGATIVE OR ZERO VOLUMETRIC HEAT AND
C    THERMAL CONDUCTIVITY
        IF(SPHT(I,J).LE.0.0) GO TO 761
        IF(COND(I,J).LE.0.0) GO TO 763
      GO TO 765
761   WRITE(6,762) J,I
762   FORMAT(////,2X,30HNEGATIVE OR ZERO VOLUMETRIC HEAT, CHECK
     1 6H INPUT,(,2I3,6H CELL))
      STOP
763   WRITE(6,764) J,I
764   FORMAT(////,2X,30HNEGATIVE OR ZERO THERMAL CONDUCTIVITY,
     1 12H CHECK INPUT,  1H(,2I3,6H CELL))
      STOP
765   CONTINUE
C-----------------------------------------------------------------
C.    COMPUTE TEMP AT LOWER BOUNDARY ACCORDING TO SPECIFIED COND
C-----------------------------------------------------------------
770   GO TO (771,773,775,777), LBOND
771   DO 772 I=1,NN
772   TBBL(I,K+1)=TBBL(I,1)
      GO TO 800
773   DO 774 I=1,NN
774   TBBL(I,K+1)=T(I,M,K)
      GO TO 800
775   DO 776 I=1,NN
776   TBBL(I,K+1)=T(I,M,K)
      GO TO 800
777   DO 778 I=1,NN
778   TBBL(I,K+1)=BONDL
C-----------------------------------------------------------------
C     COMPUTE TEMPERATURE BY CALLING CORRESPONDING SUBROUTINE
C     ACCORDING TO CALCULATED RELATIVE GRADIENT, D
C-----------------------------------------------------------------
800   DO 870 J=1,M
      II=1
821   IF(Z(II,J).GE.0.1) GO TO 822
      II=II+1
      GO TO 821
822   NJ=N(J)+II-1
      DO 870 I=II,NJ
      ITYPE=NTYPE(I,J)
      GO TO(801,802,803,804,805,806,807,808,809,810,811,812,813,814,
     1  815,816),ITYPE
801   CALL GRAD(T(I,J-1,K),T(I-1,J,K),T(I,J,K),T(I+1,J,K),T(I,J+1,K)
     1  ,COND(I,J-1),COND(I-1,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I+1,J),GD)
      GO TO 830
802   CALL GRAD(T(I,J-1,K),T(I,J,K),T(I,J,K),T(I+1,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I,J),X(I,J),X(I+1,J),GD)
      GO TO 830
803   CALL GRAD(T(I,J-1,K),T(I-1,J,K),T(I,J,K),T(I,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I,J),GD)
      GO TO 830
804   CALL GRAD(TBB(I,K),T(I-1,J,K),T(I,J,K),T(I+1,J,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I+1,J),GD)
      GO TO 830
805   CALL GRAD(TBB(I,K),T(I,J,K),T(I,J,K),T(I+1,J,K),T(I,J+1,K),
     1  1.0,COND(I,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I,J),X(I,J),X(I+1,J),GD)
      GO TO 830
806   CALL GRAD(TBB(I,K),T(I-1,J,K),T(I,J,K),T(I,J,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I,J),GD)
      GO TO 830
807   CALL GRAD(TBB(I,K),T(I-1,J,K),T(I,J,K),TBB(I+1,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),1.0,COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),0.0,GD)
      GO TO 830
808   CALL GRAD(T(I,J-1,K),T(I-1,J,K),T(I,J,K),T(I+1,J,K),TBBL(I,K)
     1  ,COND(I,J-1),COND(I-1,J),COND(I,J),COND(I+1,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I-1,J),X(I,J),X(I+1,J),GD)
      GO TO 830
809   CALL GRAD(T(I,J-1,K),T(I,J,K),T(I,J,K),T(I+1,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I,J),COND(I,J),COND(I+1,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I,J),X(I,J),X(I+1,J),GD)
      GO TO 830
810   CALL GRAD(T(I,J-1,K),T(I-1,J,K),T(I,J,K),T(I,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I-1,J),X(I,J),X(I,J),GD)
      GO TO 830
811   CALL GRAD(TBB(I,K),T(I-1,J,K),T(I,J,K),T(I+1,J,K),TBBL(I,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I+1,J),1.0,
     2  0.0,Z(I,J),0.0,X(I-1,J),X(I,J),X(I+1,J),GD)
      GO TO 830
812   CALL GRAD(TBB(I,K),T(I-1,J,K),T(I,J,K),T(I,J,K),TBBL(I,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I,J),1.0,
     2  0.0,Z(I,J),0.0,X(I-1,J),X(I,J),X(I,J),GD)
      GO TO 830
813   CALL GRAD(TBB(I,K),T(I,J,K),T(I,J,K),TBB(I+1,K),T(I,J+1,K),
     1  1.0,COND(I,J),COND(I,J),1.0,COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I,J),X(I,J),0.0,GD)
      GO TO 830
814   CALL GRAD(T(I,J-1,K),T(I-1,J,K),T(I,J,K),TBB(I+1,K),T(I,J+1,K)
     1  ,COND(I,J-1),COND(I-1,J),COND(I,J),1.0,COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),0.0,GD)
```

```
            GO TO 830
      815   CALL GRAD(TBB(I,K),TBB(I-1,K),T(I,J,K),T(I+1,J,K),T(I,J+1,K),
           1  1.0,1.0,COND(I,J),COND(I+1,J),COND(I,J+1),
           2  0.0,Z(I,J),Z(I,J+1),0.0,X(I,J),X(I+1,J),GD)
            GO TO 830
      816   CALL GRAD(TBB(I,K),TBB(I-1,K),T(I,J,K),T(I,J,K),T(I,J+1,K),
           1  1.0,1.0,COND(I,J),COND(I,J),COND(I,J+1),
           2  0.0,Z(I,J),Z(I,J+1),0.0,X(I,J),X(I,J),GD)
      830   D=GD
            IF(DTTMIN(I,J).NE.DT) GO TO 840
            IF(D.GT.0.00001) GO TO 850
            IF(D.LT.-0.00001) GO TO 860
            T(I,J,K+1)=T(I,J,K)
            GO TO 870
      840   NDT=DT/DTTMIN(I,J)+0.01
            TJK=T(I,J,K)
            CALL STYRO(ITYPE,TJK,TT,NDT)
            T(I,J,K+1)=TT
            GO TO 870
      850   TJK=T(I,J,K)
            INSUL=1
            CALL WARM(ITYPE,TJK,TT,INSUL)
            T(I,J,K+1)=TT
            GO TO 870
      860   TJK=T(I,J,K)
            INSUL=1
            CALL COOL(ITYPE,TJK,TT,INSUL)
            T(I,J,K+1)=TT
      870   CONTINUE
      C**************************************************************
      C**    WRITE OUTPUT
      C**************************************************************
      900   KK=KK+1
            CALL OUTPUT(KK,NM,DTK,DTOUT,TB)
            IF(K.GE.KTK) GO TO 901
            K=K+1
            GO TO 742
      901   TOTAL=TOTAL+TIME
      999   CONTINUE
      C--------------------------------------------------------------
      C    FORMAT
      C--------------------------------------------------------------
      9     FORMAT(18A4)
      10    FORMAT(17I5)
      11    FORMAT(3I5,6F10.4)
      12    FORMAT(3F10.4)
      13    FORMAT(5F10.4,1I5)
      14    FORMAT(12F6.2)
      15    FORMAT(2I5,6F10.4)
      16    FORMAT(8F10.4)
      18    FORMAT(I5,F10.4)
            END
      C
      C
      C
            SUBROUTINE CURVE(C,AA,BB)
            DIMENSION X(15), Y(15), A(100), B(100)
            READ(5,11) N
            P=0.000001
            READ(5,12) (X(I),Y(I), I=1,N)
            READ(5,12) C
      2     A(1)=0.25
            B(1)=-4.0
      3     K=1
      100   F=0.
            G=0.
            FA=0.
            FB=0.
            GA=0.
            GB=0.
            DO 101 I=1,N
            E=EXP(A(K)*X(I)+B(K))
            F=F+(Y(I)-C+E)*(X(I)*E)
            G=G+(Y(I)-C+E)*E
            FA=FA+X(I)*(X(I)*Y(I)*E-X(I)*E*C+2.0*X(I)*E**2)
            FB=FB+X(I)*(Y(I)*E-C*E+2.0*E**2)
            GA=FB
      101   GB=GB+(Y(I)*E-C*E+2.0*E**2)
            D=FA*GB-FB*GA
            DELTA=(G*FB-F*GB)/D
            EPSI=(F*GA-G*FA)/D
            A(K+1)=A(K)+DELTA
            B(K+1)=B(K)+EPSI
            ERRA=ABS(A(K+1)-A(K))
            ERRB=ABS(B(K+1)-B(K))
            IF(ERRA.LE.P.AND.ERRB.LE.P) GO TO 102
      103   K=K+1
            GO TO 100
      102   KK=K+1
            AA=A(KK)
            BB=B(KK)
      11    FORMAT(I5)
      12    FORMAT(2F10.4)
            RETURN
            END
      C
      C
```

```
C
      SUBROUTINE GRAD(T12,T21,T22,T23,T32,K12,K21,K22,K23,K32,Z1,Z2,
     1  Z3,X1,X2,X3,D)
C*****************************************************************
C**  THIS SUBROUTINE IS PREPARED FOR COMPUTING RELATIVE
C**   GRADIENT FOR THE CELL CALLED, FROM WHICH THE TEMPERATURE
C**  IS GOING TO INCREASE OF DECREASE WILL BE KNOWN
C*****************************************************************
      REAL K12,K22,K32,K21,K23
      T1=(T32-T22)/(Z3/K32+Z2/K22)
      T2=(T22-T12)/(Z2/K22+Z1/K12)
      T3=(T23-T22)/(X3/K23+X2/K22)
      T4=(T22-T21)/(X2/K22+X1/K21)
      D=(T1-T2)/Z2+(T3-T4)/X2
      RETURN
      END
C
C
C
      SUBROUTINE STYRO(ITYPE,TJK,TTT,NDT)
      COMMON /BLOCK/I,J,K,M,DT,D,NWS,DTK1,DF
      COMMON /BLK1/T(12,12,30),ID(180),NTYPE(12,12),N(12)
      COMMON /BLK2/DEN(12,12),WC(12,12),SPHT(12,12),COND(12,12)
      COMMON /BLK4/C5(12,12),C6(12,12),C7(12,12),ICE(12,12)
      COMMON /BLK5/X(12,12),Z(12,12),DTTHIN(12,12)
      COMMON /BLK6/TBB(12,100),TBBL(12,100)
      INSUL=2
      IF (ABS(D).GT.0.00001) GO TO 10
      TTT=T(I,J,K)
      RETURN
10    IF(D.GT.0.00001) JD=1
      IF(D.LT.-0.00001) JD=2
      DO 11 NTHIN=1,NDT
      IF(JD.EQ.1) CALL WARM(ITYPE,TJK,TT,INSUL)
      IF(JD.EQ.2) CALL COOL(ITYPE,TJK,TT,INSUL)
      TJK=TT
      GO TO(101,102,103,104,105,106,107,108,109,110,111,112,113,114,
     1  115,116),ITYPE
101    CALL GRAD(T(I,J-1,K),T(I-1,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I+1,J),GD)
       GO TO 120
102    CALL GRAD(T(I,J-1,K),T(I,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I,J),X(I,J),X(I+1,J),GD)
       GO TO 120
103    CALL GRAD(T(I,J-1,K),T(I-1,J,K),TJK,T(I,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I,J),GD)
       GO TO 120
104    CALL GRAD(TBB(I,K),T(I-1,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I+1,J),GD)
       GO TO 120
105    CALL GRAD(TBB(I,K),T(I,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,COND(I,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I,J),X(I,J),X(I+1,J),GD)
       GO TO 120
106    CALL GRAD(TBB(I,K),T(I-1,J,K),TJK,T(I,J,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I,J),GD)
       GO TO 120
107    CALL GRAD(TBB(I,K),T(I-1,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),1.0,COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),0.0,GD)
       GO TO 120
108    CALL GRAD(T(I,J-1,K),T(I-1,J,K),TJK,T(I+1,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I+1,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I-1,J),X(I,J),X(I+1,J),GD)
       GO TO 120
109    CALL GRAD(T(I,J-1,K),T(I,J,K),TJK,T(I+1,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I,J),COND(I,J),COND(I+1,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I,J),X(I,J),X(I+1,J),GD)
       GO TO 120
110    CALL GRAD(T(I,J-1,K),T(I-1,J,K),TJK,T(I,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I-1,J),X(I,J),X(I,J),GD)
       GO TO 120
111    CALL GRAD(TBB(I,K),T(I-1,J,K),TJK,T(I+1,J,K),TBBL(I,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I+1,J),1.0,
     2  0.0,Z(I,J),0.0,X(I-1,J),X(I,J),X(I+1,J),GD)
       GO TO 120
112    CALL GRAD(TBB(I,K),T(I-1,J,K),TJK,T(I,J,K),TBBL(I,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I,J),1.0,
     2  0.0,Z(I,J),0.0,X(I-1,J),X(I,J),X(I,J),GD)
       GO TO 120
113    CALL GRAD(TBB(I,K),T(I,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  1.0,COND(I,J),COND(I,J),1.0,COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I,J),X(I,J),0.0,GD)
       GO TO 120
114    CALL GRAD(T(I,J-1,K),T(I-1,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),1.0,COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),0.0,GD)
       GO TO 120
```

```
115   CALL GRAD(TBB(I,K),TBB(I-1,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,1.0,COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),0.0,X(I,J),X(I+1,J),GD)
      GO TO 120
116   CALL GRAD(TBB(I,K),TBB(I-1,K),TJK,T(I,J,K),T(I,J+1,K),
     1  1.0,1.0,COND(I,J),COND(I,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),0.0,X(I,J),X(I,J),GD)
      GO TO 120
120   D=GD
      IF(ABS(D).LE.0.00001) GO TO 20
11    CONTINUE
20    TTT=TT
      RETURN
      END
C
C
C
      SUBROUTINE WARM(ITYPE,TJK,TTT,INSUL)
      COMMON /BLOCK/I,J,K,M,DT,D,NWS,DTK1,DF
      COMMON /BLK1/T(12,12,30),ID(180),NTYPE(12,12),N(12)
      COMMON /BLK2/DEN(12,12),WC(12,12),SPHT(12,12),COND(12,12)
      COMMON /BLK4/C5(12,12),C6(12,12),C7(12,12),ICE(12,12)
      COMMON /BLK5/X(12,12),Z(12,12),DTTMIN(12,12)
      COMMON /BLK6/TBB(12,100),TBBL(12,100)
      DATA TFREZ,P/32.0,0.001/,QL/144.0/
      MMM=0
      IF(WC(I,J).EQ.0.0) GO TO 10
      IF(TJK.GE.TFREZ) GO TO 10
      HL=QL*DEN(I,J)*WC(I,J)/SPHT(I,J)/100.0
      EXPK=(C5(I,J)-EXP(C6(I,J)*TJK+C7(I,J)))/100.0
      DTF=(SPHT(I,J)*(TFREZ-TJK)+HL*EXPK)/(2.0*D)
      IF(INSUL.EQ.1) GO TO 5
      IF(DTF-DTTMIN(I,J)) 20,30,40
5     IF(DTF-DT)20,30,40
30    TTT=TFREZ
      RETURN
10    IF(INSUL.EQ.1) DT2=DT
      IF(INSUL.EQ.2) DT2=DTTMIN(I,J)
11    GO TO(101,102,103,104,105,106,107,108,109,110,111,112,113,114,
     1  115,116),ITYPE
101   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
102   CALL DIRECT(T(I,J-1,K),T(I,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
103   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,T(I,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
104   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
105   CALL DIRECT(TBB(I,K),T(I,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,COND(I,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
106   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,T(I,J,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
107   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),1.0,COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),0.0,
     3  SPHT(I,J),DT2,TT)
      GO TO 120
108   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,T(I+1,J,K),TBBL(I,K)
     1  ,COND(I,J-1),COND(I-1,J),COND(I,J),COND(I+1,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I-1,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
109   CALL DIRECT(T(I,J-1,K),T(I,J,K),TJK,T(I+1,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I,J),COND(I,J),COND(I+1,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
110   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,T(I,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I-1,J),X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
111   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,T(I+1,J,K),TBBL(I,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I+1,J),1.0,
     2  0.0,Z(I,J),0.0,X(I-1,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
```

```
      GO TO 120
112   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,T(I,J,K),TBBL(I,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I,J),1.0,
     2  0.0,Z(I,J),0.0,X(I-1,J),X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
113   CALL DIRECT(TBB(I,K),T(I,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  1.0,COND(I,J),COND(I,J),1.0,COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I,J),X(I,J),0.0,
     3  SPHT(I,J),DT2,TT)
      GO TO 120
114   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),1.0,COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),0.0,
     3  SPHT(I,J),DT2,TT)
      GO TO 120
115   CALL DIRECT(TBB(I,K),TBB(I-1,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,1.0,COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),0.0,X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
116   CALL DIRECT(TBB(I,K),TBB(I-1,K),T(I,J,K),T(I,J,K),T(I,J+1,K),
     1  1.0,1.0,COND(I,J),COND(I,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),0.0,X(I,J),X(I,J),SPHT(I,J),DT2,TT)
      GO TO 120
120   TTT=TT
      IF(MMM.NE.0) GO TO 70
      RETURN
20    IF(INSUL.EQ.1) DT2=DT-DTF
      IF(INSUL.EQ.2) DT2=DTTMIN(I,J)-DTF
      TJK=TFREZ
      GO TO 11
40    IF(INSUL.EQ.1) DT2=DT
      IF(INSUL.EQ.2) DT2=DTTMIN(I,J)
      MMM=MMM+1
      GO TO 11
70    TAB=TT
      EXPK=EXP(C6(I,J)*TJK+C7(I,J))/100.0
      T1=TJK-100.0*P
80    EXPK1=EXP(C6(I,J)*T1+C7(I,J))/100.0
      TTT=T1-(T1-TAB+HL*(EXPK1-EXPK))/(1.0+HL*C6(I,J)*EXPK1)
      IF(ABS(TTT-T1).LE.P) RETURN
      T1=TTT
      GO TO 80
      END
      SUBROUTINE COOL(ITYPE,TJK,TTT,INSUL)
      COMMON /BLOCK/I,J,K,M,DT,D,NWS,DTK1,DF
      COMMON /BLK1/T(12,12,30),ID(150),NTYPE(12,12),N(12)
      COMMON /BLK2/DEN(12,12),WC(12,12),SPHT(12,12),COND(12,12)
      COMMON /BLK4/C5(12,12),C6(12,12),C7(12,12),ICE(12,12)
      COMMON /BLK5/X(12,12),Z(12,12),DTTMIN(12,12)
      COMMON /BLK6/TBB(12,100),TBBL(12,100)
      DATA TFREZ,P/32.0,0.001/, HL/144.0/
      MMM=0
      IF(WC(I,J).EQ.0.0) GO TO 10
      IF(TJK.LE.TFREZ) GO TO 20
      DTF=SPHT(I,J)*(TFREZ-TJK)/(2.0*D)
      IF(INSUL.EQ.1) GO TO 5
      IF(DTF-DTTMIN(I,J)) 30,50,10
5     IF(DTF-DT) 30,50,10
50    TTT=TFREZ
      RETURN
10    IF(INSUL.EQ.1) DT2=DT
      IF(INSUL.EQ.2) DT2=DTTMIN(I,J)
11    GO TO(101,102,103,104,105,106,107,108,109,110,111,112,113,114,
     1  115,116),ITYPE
101   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
102   CALL DIRECT(T(I,J-1,K),T(I,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
103   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,T(I,J,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I,J),COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
104   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
105   CALL DIRECT(TBB(I,K),T(I,J,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,COND(I,J),COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
106   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,T(I,J,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
107   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  1.0,COND(I-1,J),COND(I,J),1.0,COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),0.0,
     3  SPHT(I,J),DT2,TT)
      GO TO 120
108   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,T(I+1,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I+1,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I-1,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
109   CALL DIRECT(T(I,J-1,K),T(I,J,K),TJK,T(I+1,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I,J),COND(I,J),COND(I+1,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
110   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,T(I,J,K),TBBL(I,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),COND(I,J),1.0,
     2  Z(I,J-1),Z(I,J),0.0,X(I-1,J),X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
111   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,T(I+1,J,K),TBBL(I,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I+1,J),1.0,
     2  0.0,Z(I,J),0.0,X(I-1,J),X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
112   CALL DIRECT(TBB(I,K),T(I-1,J,K),TJK,T(I,J,K),TBBL(I,K),
     1  1.0,COND(I-1,J),COND(I,J),COND(I,J),1.0,
     2  0.0,Z(I,J),0.0,X(I-1,J),X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
113   CALL DIRECT(TBB(I,K),T(I,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  1.0,COND(I,J),COND(I,J),1.0,COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),X(I,J),X(I,J),0.0,
     3  SPHT(I,J),DT2,TT)
      GO TO 120
114   CALL DIRECT(T(I,J-1,K),T(I-1,J,K),TJK,TBB(I+1,K),T(I,J+1,K),
     1  COND(I,J-1),COND(I-1,J),COND(I,J),1.0,COND(I,J+1),
     2  Z(I,J-1),Z(I,J),Z(I,J+1),X(I-1,J),X(I,J),0.0,
     3  SPHT(I,J),DT2,TT)
      GO TO 120
115   CALL DIRECT(TBB(I,K),TBB(I-1,K),TJK,T(I+1,J,K),T(I,J+1,K),
     1  1.0,1.0,COND(I,J),COND(I+1,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),0.0,X(I,J),X(I+1,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
116   CALL DIRECT(TBB(I,K),TBB(I-1,K),TJK,T(I,J,K),T(I,J+1,K),
     1  1.0,1.0,COND(I,J),COND(I,J),COND(I,J+1),
     2  0.0,Z(I,J),Z(I,J+1),0.0,X(I,J),X(I,J),
     3  SPHT(I,J),DT2,TT)
      GO TO 120
120   TTT=TT
      IF([redacted].NE.0) GO TO 70
      RETURN
20    IF(INSUL.EQ.1) DT2=DT
      IF(INSUL.EQ.2) DT2=DTTHIN(I,J)
      T1=TJK-100.0*P
      GO TO 50
30    IF(INSUL.EQ.1) DT2=DT-DTF
      IF(INSUL.EQ.2) DT2=DTTHIN(I,J)-DTF
      TJK=TFREZ
      T1=TFREZ-100.0*P
50    [redacted]+1
      GO TO 11
70    TAB=TT
      HL=OL*DEN(I,J)*WC(I,J)/SPHT(I,J)/100.0
      EXPK=EXP(C6(I,J)*TJK+C7(I,J))/100.0
60    EXPK1=EXP(C6(I,J)*T1+C7(I,J))/100.0
      TTT=T1-(T1-TAB+HL*(EXPK1-EXPK))/(1.0+HL*C6(I,J)*EXPK1)
      IF(ABS(TTT-T1).LE.P) RETURN
      T1=TTT
      GO TO 60
      END
      SUBROUTINE DIRECT(T12,T21,T22,T23,T32,K12,K21,K22,K23,K32,
     1  Z1,Z2,Z3,X1,X2,X3,SPHT,DT,TTT)
C*****************************************************************
C   COMPUTING TEMPERTURE FOR THE CELL, WITHOUT INVOLVING HEAT
C**   GENERATION OR ABSORBTION
C*****************************************************************
      REAL K12,K21,K22,K23,K32
      AB=2.0*DT/SPHT/Z2
      AB1=Z3/K32
      AB2=Z2/K22
      AB3=Z1/K12
      CD=2.0*DT/SPHT/X2
      CD1=X3/K23
      CD2=X2/K22
      CD3=X1/K21
      A=AB/(AB1+AB2)
      B=AB/(AB2+AB3)
      C=CD/(CD1+CD2)
      D=CD/(CD2+CD3)
      TTT=A*(T22-T22)-B*(T22-T12)+C*(T23-T22)-D*(T22-T21)+T22
      RETURN
      END
      FUNCTION VH(T,A,B,DEN,WC,PARTF,PARTU)
```

```
C*****************************************************************
C**   COMPUTING VOLUMETRIC HEAT OF THE CELL AT SPECIFIED
C**   TEMPERATURES AND AMOUNT OF WATER FROZEN
C*****************************************************************
      DATA SPHTW,SPHTI/1.0,0.48/
      IF(WC.EQ.0.0) GO TO 1
      VH=A*T+B+DEN*(WC/100.0)*(SPHTW*PARTU+SPTHI*PARTF)
C     VH=B
C     IF(T.GT.32.0) VH=A
      RETURN
1     VH=A*T+B
      RETURN
      END
      FUNCTION TC(T,A,B,DEN,WC,PARTF,PARTU)
C************************************************************
C**   COMPUTING THERMAL CONDUCTIVITY OF THE CELL AT
C**   SPECIFIED TEMPERATURE AND AMOUNT OF WATER FROZEN
C************************************************************
       DATA TCW,TCI/0.345,1.284/,SPWT/2.70/
       IF(WC.EQ.0.0) GO TO 1
       C=DEN/SPWT
       D=DEN*WC/100.0
       TC=C/(C+D)*(A*T+B)+D/(C+D)*(TCI*PARTF+TCW*PARTU)
C      TC=B
C      IF(T.LT.32) TC=A
       RETURN
1      TC=A*T+B
       RETURN
       END
       SUBROUTINE HOUR(DT,CELL,THOUR,TOTAL,LTIME,TIME)
C************************************************************
C**   COMPUTE DURATION OF TIME
C************************************************************
       ITIME=DT*CELL/24.0
       TIME=ITIME*24
       IF(TIME.LT.24.0) TIME=DT*CELL
       TOUR=THOUR-TOTAL
       IF(TIME.GE.TOUR) TIME=TOUR
      LTIME=TOUR/TIME+0.99
      NDAY=TOUR/24.0
      NHOUR=TOUR-FLOAT(NDAY)*24.0
      WRITE(6,1) TOUR,NDAY,NHOUR
1     FORMAT(//2X,24HTOTAL DURATION OF TIME =,F7.1,8H HOURS =, I4,
     1  9H DAYS AND, I3,6H HOURS)
      RETURN
      END
C
      SUBROUTINE OUTPUT(KK,NM,DTK,DTOUT,TB)
C*****************************************************************
C**   WRITE OUTPUT
C*****************************************************************
       DIMENSION TB(100)
       COMMON /BLOCK/I,J,K,M,DT,D,NWS,DTK1,DF
       COMMON /BLK1/T(12,12,30),ID(180),NTYPE(12,12),N(12)
       COMMON /BLK5/X(12,12),Z(12,12),DTTMIN(12,12)
       COMMON /BLK6/TBB(12,100),TBBL(12,100)
       IF(KK.EQ.0) GO TO 100
       DTK=DTK+DT
       DTK1=DTK
       IF(DTK.LT.DTOUT) RETURN
      OUT=DTK/DTOUT
      LOUT=DTK/DTOUT+0.001
      IF(ABS(OUT-FLOAT(LOUT)).GT.0.001) RETURN
      WRITE(6,57) DTK,TB(K+1)
      GO TO 30
100   K=0
      WRITE(6,52) DTK,TB(K+1)
30    WRITE(6,51) (I,I=1,NM)
      DO 1 II=1,M
      IF(X(II,1).GE.0.1) GO TO 9999
1     CONTINUE
9999  NJ=N(1)+II-1
      GO TO(101,102,103,104,105,106,107,108,109,110,110),II
101   WRITE(6,121) (TBB(I,K+1), I=1,NJ)
      GO TO 3
102   WRITE(6,122) (TBB(I,K+1), I=2,NJ)
      GO TO 3
103   WRITE(6,123) (TBB(I,K+1), I=3,NJ)
      GO TO 3
104   WRITE(6,124) (TBB(I,K+1), I=4,NJ)
      GO TO 3
105   WRITE(6,125) (TBB(I,K+1), I=5,NJ)
      GO TO 3
106   WRITE(6,126) (TBB(I,K+1), I=6,NJ)
      GO TO 3
107   WRITE(6,127) (TBB(I,K+1), I=7,NJ)
      GO TO 3
108   WRITE(6,128) (TBB(I,K+1), I=8,NJ)
      GO TO 3
109   WRITE(6,129) (TBB(I,K+1), I=9,NJ)
      GO TO 3
110   WRITE(6,130) (TBB(I,K+1), I=10,NJ)
      GO TO 3
121    FORMAT(1X,14HUPPER BOUNDARY, 2X,14F8.2)
122    FORMAT(1X,14HUPPER BOUNDARY, 8X,13F8.2)
```

```
123   FORMAT(1X,14HUPPER BOUNDARY,14X,12F6.2)
124   FORMAT(1X,14HUPPER BOUNDARY,20X,11F6.2)
125   FORMAT(1X,14HUPPER BOUNDARY,26X,10F6.2)
126   FORMAT(1X,14HUPPER BOUNDARY,32X, 9F6.2)
127   FORMAT(1X,14HUPPER BOUNDARY,38X, 8F6.2)
128   FORMAT(1X,14HUPPER BOUNDARY,44X, 7F6.2)
129   FORMAT(1X,14HUPPER BOUNDARY,50X, 6F6.2)
130   FORMAT(1X,14HUPPER BOUNDARY,56X, 5F6.2)
3     DO 10 J=1,M
      II=1
5     IF(X(II,J).GE.0.1) GO TO 4
      II=II+1
      GO TO 5
4     NJ=N(J)+II-1
      IF(NJ.LT.NN) GO TO 20
      GO TO (141,142,143,144,145,146,147,148,149,150),II
141   WRITE(6,161)J,(T(I,J,K+1),I=1,NJ),T(NJ,J,K+1)
      GO TO 10
142   WRITE(6,161)J,TBB(1,K+1),(T(I,J,K+1), I=2,NJ),T(NJ,J,K+1)
      GO TO 10
143   WRITE(6,163)J,TBB(2,K+1),(Y(I,J,K+1), I=3,NJ),T(NJ,J,K+1)
      GO TO 10
144   WRITE(6,164)J,TBB(3,K+1),(T(I,J,K+1), I=4,NJ),T(NJ,J,K+1)
      GO TO 10
145   WRITE(6,165)J,TBB(4,K+1),(T(I,J,K+1), I=5,NJ),T(NJ,J,K+1)
      GO TO 10
146   WRITE(6,166)J,TBB(5,K+1),(T(I,J,K+1), I=6,NJ),T(NJ,J,K+1)
      GO TO 10
147   WRITE(6,167)J,TBB(6,K+1),(T(I,J,K+1), I=7,NJ),T(NJ,J,K+1)
      GO TO 10
148   WRITE(6,168)J,TBB(7,K+1),(T(I,J,K+1), I=8,NJ),T(NJ,J,K+1)
      GO TO 10
149   WRITE(6,169)J,TBB(8,K+1),(T(I,J,K+1), I=9,NJ),T(NJ,J,K+1)
      GO TO 10
150   WRITE(6,170)J,TBB(9,K+1),(T(I,J,K+1), I=10,NJ),T(NJ,J,K+1)
      GO TO 10
20    N1=NJ+1
      IF(J.LT.M) N2=N(J+1)
      IF(J.EQ.M) N2=NN
      GO TO (181,182,183,184,185,186,187,188,189,190),II
181   WRITE(6,161)J,(T(I,J,K+1), I=1,NJ), (TBB(NN,K+1),NN=N1,N2)
      GO TO 10
182   WRITE(6,161) J, TBB(1,K+1), (T(I,J,K+1), I=2,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
183   WRITE(6,163) J, TBB(2,K+1), (T(I,J,K+1), I=3,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
184   WRITE(6,164) J, TBB(3,K+1), (T(I,J,K+1), I=4,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
185   WRITE(6,165) J, TBB(4,K+1), (T(I,J,K+1), I=5,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
186   WRITE(6,166) J, TBB(5,K+1), (T(I,J,K+1), I=6,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
187   WRITE(6,167) J, TBB(6,K+1), (T(I,J,K+1), I=7,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
188   WRITE(6,168) J, TBB(7,K+1), (T(I,J,K+1), I=8,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
189   WRITE(6,169) J, TBB(8,K+1), (T(I,J,K+1), I=9,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
190   WRITE(6,170) J, TBB(9,K+1), (T(I,J,K+1), I=10,NJ),
     1  (TBB(NN,K+1), NN=N1,N2)
      GO TO 10
10    CONTINUE
161   FORMAT(3X,5HLAYER,I3, 6X,15F6.2)
163   FORMAT(3X,5HLAYER,I3,12X,14F6.2)
164   FORMAT(3X,5HLAYER,I3,18X,13F6.2)
165   FORMAT(3X,5HLAYER,I3,24X,12F6.2)
166   FORMAT(3X,5HLAYER,I3,30X,11F6.2)
167   FORMAT(3X,5HLAYER,I3,36X,10F6.2)
168   FORMAT(3X,5HLAYER,I3,42X, 9F6.2)
169   FORMAT(3X,5HLAYER,I3,48X, 8F6.2)
170   FORMAT(3X,5HLAYER,I3,54X, 7F6.2)
      WRITE(6,56) (TBBL(I,K+1), I=1,NN)
51    FORMAT(/15X,15I6)
52    FORMAT(1H1,10X,18HTIME AT THIS STEP=,F6.2,6H  HRS ,
     1  10X,18HAIR TEMPERATURE=, F6.2)
56    FORMAT(1X,14HLOWER BOUNDARY,2X,15F6.2)
57    FORMAT(////10X,18HTIME AT THIS STEP=,F6.2,6H  HRS ,
     1  10X,18HAIR TEMPERATURE=, F6.2)
C     CALL HEAVE(DTOUT,HVT)
      RETURN
      END

      SUBROUTINE OUT(IN)
C************************************************************
C**   WRITE OUT INPUT INFORMATIONS
C************************************************************
      COMMON /BLOCK/I,J,K,M,DT,D,NNS,DTK1,DF
      COMMON /BLK1/T(12,12,30),ID(180),NTYPE(12,12),N(12)
      COMMON /BLK2/DEN(12,12),WC(12,12),SPHT(12,12),COND(12,12)
      COMMON /BLK3/C1(12,12),C2(12,12),C3(12,12),C4(12,12)
      COMMON /BLK4/C5(12,12),C6(12,12),C7(12,12),ICE(12,12)
      COMMON /BLK5/X(12,12),Z(12,12),DTTMIN(12,12)
      COMMON /BLK6/TBB(12,100),TBBL(12,100)
      COMMON /BLK7/INIT,TINIT,TIB(12)
      COMMON /BLK8/IBOND,BOND,ABOND,BBOND,CBOND,DBOND,HALFT,NSTEP,TBUILD
      COMMON /BLK10/STEPA(365),STEPB(365),STEPT(365)
      COMMON /BLK9/LBOND,BONDL
      MM=N(M)
      GO TO(100,200,300,400,500,600,700,800), IN
C-----------------------------------------------------------------------
C   WRITE ID,TYPE,THICKNESS,WIDTH,DRY DENSITY, AND WATER CONTENT
C-----------------------------------------------------------------------
100   WRITE(6,101)
101   FORMAT(1H1,47HDATA FOR PREDICTING OF FROST PENETRATION INTO A,
     1  18H SOIL-WATER SYSTEM///)
C     WRITE(6,10) ID
10    FORMAT(18A4)
      WRITE(6,102) (I,I=1,MM)
102   FORMAT(///,20X,43HWIDTH(X), THICKNESS(Z), IN INCHES, AND TYPE,
     1  12H OF THE CELL//1X,9HZ(J)/X(I),5X,14I8)
      WRITE(6,103) (X(I,M),I=1,MM)
103   FORMAT(11X,8HWIDTH ,14F8.2)
      WRITE(6,104)
104   FORMAT(9X,9HTHICKNESS)
      DO 11 J=1,M
      II=1
14    IF(X(II,J).GE.0.01) GO TO 13
      II=II+1
      GO TO 14
13    NJ=N(J)+II-1
      GO TO(121,122,123,124,125,126,127,128,129,130),II
121   WRITE(6,141)J,Z(1,J),(NTYPE(I,J), I=1,NJ)
      GO TO 11
122   WRITE(6,142)J,Z(2,J),(NTYPE(I,J), I=2,NJ)
      GO TO 11
123   WRITE(6,143)J,Z(3,J),(NTYPE(I,J), I=3,NJ)
      GO TO 11
124   WRITE(6,144)J,Z(4,J),(NTYPE(I,J), I=4,NJ)
      GO TO 11
125   WRITE(6,145)J,Z(5,J),(NTYPE(I,J), I=5,NJ)
      GO TO 11
126   WRITE(6,146)J,Z(6,J),(NTYPE(I,J), I=6,NJ)
      GO TO 11
127   WRITE(6,147)J,Z(7,J),(NTYPE(I,J), I=7,NJ)
      GO TO 11
128   WRITE(6,148)J,Z(8,J),(NTYPE(I,J), I=8,NJ)
      GO TO 11
129   WRITE(6,149)J,Z(9,J),(NTYPE(I,J), I=9,NJ)
      GO TO 11
130   WRITE(6,150)J,Z(10,J),(NTYPE(I,J), I=10,NJ)
      GO TO 11
11    CONTINUE
141   FORMAT(/I5,F11.3,I6,12I8)
142   FORMAT(/I5,F11.3, 6X,12I8)
143   FORMAT(/I5,F11.3,14X,11I8)
144   FORMAT(/I5,F11.3,22X,10I8)
145   FORMAT(/I5,F11.3,30X, 9I8)
146   FORMAT(/I5,F11.3,38X, 8I8)
147   FORMAT(/I5,F11.3,46X, 7I8)
148   FORMAT(/I5,F11.3,54X, 6I8)
149   FORMAT(/I5,F11.3,62X, 5I8)
150   FORMAT(/I5,F11.3,70X, 4I8)
      WRITE(6,105) (I,I=1,MM)
105   FORMAT(////20X,44HUNIT WEIGHT (PCF) AND WATER CONTENT (PERCENT
     1 15H) AT VARIOUS CELLS//
     2 1X,9HZ(J)/X(I),14I8)
      DO 12 J = 1,M
      II=1
15    IF(X(II,J).GE.0.1) GO TO 16
      II=II+1
16    NJ=N(J)+II-1
      GO TO(161,162,163,164,165,166,167,168,169,170),II
161   WRITE(6,181) J,(DEN(I,J), I=1,NJ)
      WRITE(6,1811) (WC(I,J), I=1,NJ)
      GO TO 12
162   WRITE(6,182) J,(DEN(I,J), I=2,NJ)
      WRITE(6,1812) (WC(I,J), I=2,NJ)
      GO TO 12
163   WRITE(6,183) J,(DEN(I,J), I=3,NJ)
      WRITE(6,1813) (WC(I,J), I=3,NJ)
      GO TO 12
164   WRITE(6,184) J,(DEN(I,J), I=4,NJ)
      WRITE(6,1814) (WC(I,J), I=4,NJ)
      GO TO 12
165   WRITE(6,185) J,(DEN(I,J), I=5,NJ)
      WRITE(6,1815) (WC(I,J), I=5,NJ)
      GO TO 12
166   WRITE(6,186) J,(DEN(I,J), I=6,NJ)
      WRITE(6,1816) (WC(I,J), I=6,NJ)
      GO TO 12
167   WRITE(6,187) J,(DEN(I,J), I=7,NJ)
      WRITE(6,1817) (WC(I,J), I=7,NJ)
      GO TO 12
168   WRITE(6,188) J,(DEN(I,J), I=8,NJ)
      WRITE(6,1818) (WC(I,J), I=8,NJ)
      GO TO 12
169   WRITE(6,189) J,(DEN(I,J), I=9,NJ)
      WRITE(6,1819) (WC(I,J), I=9,NJ)
      GO TO 12
170   WRITE(6,190) J,(DEN(I,J), I=10,NJ)
      WRITE(6,1820) (WC(I,J), I=10,NJ)
      GO TO 12
12    CONTINUE
181   FORMAT(/I6, 6X,12F6.2)
182   FORMAT(/I6,14X,11F6.2)
183   FORMAT(/I6,22X,10F6.2)
184   FORMAT(/I6,30X, 9F6.2)
185   FORMAT(/I6,38X, 8F6.2)
186   FORMAT(/I6,46X, 7F6.2)
187   FORMAT(/I6,54X, 6F6.2)
188   FORMAT(/I6,62X, 5F6.2)
189   FORMAT(/I6,70X, 4F6.2)
190   FORMAT(/I6,78X, 3F6.2)
1811  FORMAT(12X,12F6.2)
1812  FORMAT(20X,11F6.2)
1813  FORMAT(28X,10F6.2)
1814  FORMAT(36X, 9F6.2)
1815  FORMAT(44X, 8F6.2)
1816  FORMAT(52X, 7F6.2)
1817  FORMAT(60X, 6F6.2)
1818  FORMAT(68X, 5F6.2)
1819  FORMAT(76X, 4F6.2)
1820  FORMAT(84X, 3F6.2)
      RETURN
C-----------------------------------------------------------------
C   WRITE COEFFICIENTS FOR DEFINING VOLUMTRIC HEAT AND THERMAL
C   CONDUCTIVITY OF CELLS
C------------------------------------------------------------------
200   WRITE(6,201)
201   FORMAT(/////2X,9HCELL(I,K),12X,15HVOLUMETRIC HEAT,18X,8HCONDUC
     1ENTIVITY
     1/24X,13H(BTU/CU FT/F),17X,16H(BTU/FT/HOUR/F),//)
      DO 21 J=1,M
      II=1
24    IF(X(II,J).GE.0.1) GO TO 23
      II=II+1
      GO TO 24
23    NJ=N(J)+II-1
21    WRITE(6,202) (J,I,C1(I,J),C2(I,J),C3(I,J),C4(I,J), I=II,NJ)
202   FORMAT(I7,1H,I2,10X,2HC=,F7.2,4H T +,F7.3,12X,4HK = ,F6.3,
     1  5H T + ,F6.3)
      RETURN
C---------------------------------------------------------------
C     WRITE COEFFICIENTS FOR DEFINING THE ICE FORMATION
C     CHARACTERISTICS
C---------------------------------------------------------------
300   WRITE(6,301)
301   FORMAT(/////2X,9HCELL(I,K),12X,22HICEFORMATION CURVE IN,
     1  21H EXPONENTIAL FUNCTION/)
      DO 310 J=1,M
      II=1
31    IF(X(II,J).GE.0.1) GO TO 32
      II=II+1
      GO TO 31
32    NJ=N(J)+II-1
      DO 310 I=II,NJ
      IF(ICE(I,J).EQ.3) GO TO 311
      WRITE(6,302) J,I,C5(I,J),C6(I,J),C7(I,J)
302   FORMAT(I7,1H,,I2,8X,19HPERCENT WC FROZEN ,F6.2,7H - EXP(,
     1  F6.3,12H *T(I,J,K) +,F6.3,2H ))
      GO TO 310
311   WRITE(6,303) J,I
303   FORMAT(I7,1H,,I2,10X,8HDRY CELL)
310   CONTINUE
      RETURN
C---------------------------------------------------------------
C   WRITE INITIAL CONDITION
C---------------------------------------------------------------
400   GO TO(401,402), INIT
401   WRITE(6,410)TINIT
410   FORMAT(///2X,17HINITIAL CONDITION,10X,21HINITIAL TEMPERATURE =
     1 ,25H CONSTANT FOR ALL CELLS =,F10.2,3X,17HDEGREE FAHRENHEIT)
      RETURN
402   WRITE(6,421)
      DO 41 J=1,M
      II=1
44    IF(X(II,J).GE.0.1) GO TO 43
      II=II+1
      GO TO 44
43    NJ=N(J)+II-1
      GO TO(431,432,433,434,435,436,437,438,439,440), II
431   WRITE(6,451) (T(I,J,1), I=1,NJ)
      GO TO 41
432   WRITE(6,452) (T(I,J,1), I=2,NJ)
      GO TO 41
433   WRITE(6,453) (T(I,J,1), I=3,NJ)
      GO TO 41
434   WRITE(6,454) (T(I,J,1), I=4,NJ)
      GO TO 41
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435   WRITE(6,455) (T(I,J,1), I=5,NJ)
      GO TO 41
436   WRITE(6,456) (T(I,J,1), I=6,NJ)
      GO TO 41
437   WRITE(6,457) (T(I,J,1), I=7,NJ)
      GO TO 41
438   WRITE(6,458) (T(I,J,1), I=8,NJ)
      GO TO 41
439   WRITE(6,459) (T(I,J,1), I=9,NJ)
      GO TO 41
440   WRITE(6,460) (T(I,J,1), I=10,NJ)
      GO TO 41
41    CONTINUE
451   FORMAT( 2X,14F8.2)
452   FORMAT( 8X,13F8.2)
453   FORMAT(14X,12F8.2)
454   FORMAT(20X,11F8.2)
455   FORMAT(26X,10F8.2)
456   FORMAT(32X, 9F8.2)
457   FORMAT(38X, 8F8.2)
458   FORMAT(44X, 7F8.2)
459   FORMAT(50X, 6F8.2)
460   FORMAT(56X, 5F8.2)
      WRITE(6,425) (TIB(I), I=1,MM)
      WRITE(6,426) (TBBL(I,1), I=1,MM)
421   FORMAT(///2X,17HINITIAL CONDTION/6X,23HTEMPERATURES AT CENTERS
     1 , 19H OF ALL CELLS GIVEN)
425   FORMAT(//2X,35HINITIAL UPPER BOUNDARY TEMPERATURES/1X,14F8.2)
426   FORMAT(//2X,35HINITIAL LOWER BOUNDARY TEMPERATURES/1X,14F8.2)
      RETURN
500   RETURN
C-----------------------------------------------------------------
C     WRITE UPPER BOUNDARY CONDITION
C-----------------------------------------------------------------
600   GO TO(601,602,603,604,605), IBOND
601   WRITE(6,61) BOND
61    FORMAT(//1X,19HBOUNDARY CONDITIONS,5X,21HTEMEPATURE AT BOUNDAR
     1 28HY, = CONSTANT AT ALL TIMES =,F10.3,18H DEGREE FAHRENHEIT)
      RETURN
602   WRITE(6,62) ABOND,BBOND,CBOND,DBOND
62    FORMAT(//1X,19HBOUNDARY CONDITIONS,5X,10HT(0,TIME)=,F10.4,
     1 3H +,F10.4,8H *TIME +,F10.4,10H *TIME**  ,F10.4,6H*TIME*)
      RETURN
603   WRITE(6,63) ABOND,HALFT,BBOND,HALFT
   63 FORMAT(///1X,19HBOUNDARY CONDITIONS,5X10HT(0,TIME)=,8H 32 -
     1F8.4,12H SIN(3.14*T/F8.2,3H) +F8.4,12H COS(3.14*T/F8.2,1H))
      RETURN
604   WRITE(6,64)
64    FORMAT(///1X,44HBOUNDARY CONDITIONS IN FORM OF STEP FUNCTION//
     1 12H SIN(3.14*T/F8.2,3H) +,F10.4,12H COS(3.14*T/F8.2,1H))
      WRITE(6,65)(I,STEPA(I),STEPB(I),STEPT(I),I=1,NSTEP)
65    FORMAT(I11,9X,F8.2,1X,3H - ,F8.2,11X,F8.2)
      RETURN
605   WRITE(6,66) ABOND,HALFT,TBUILD
66    FORMAT(///1X,' BOUNDRY CONDITIONS      T(0,TIME)=32.0-',F8.2,
     1 '*(SIN(3.14*T/',F8.2,')   BUILDING TEMPERATURE= ',F8.2)
      RETURN
700   RETURN
C-----------------------------------------------------------------
C   WRITE LOWER BOUNDARY CONDITIONS
C-----------------------------------------------------------------
800   GO TO(801,802,803,804), LBOND
801   WRITE(6,81) TBBL(1,1)
81    FORMAT(/1X,48HTEMPERATURE AT LOWER BOUNDARY REMAINS CONSTANT A
     1 44HT ALL THE TIME(EQUAL TO INITIAL TEMERATURE),3H =,F8.1)
      RETURN
802   WRITE(6,82)
82    FORMAT(/1X,48HASSUME THE LOWER BOUNDARY AS A PERFECT INSULATIO
     1 18HN TO THE HEAT FLOW)
803   WRITE(6,83)
83    FORMAT(/1X,40HTEMPERATURE AT LOWER BOUNDARY IS SAME AS,
     1 40H TEMPERATURE OF M LAYER, TBL(K)=T(I,M,K))
      RETURN
804   WRITE(6,84) BONDL
84    FORMAT(/1X,48HTEMP AT LOWER BDY EQUALS TO THE TEMP SPECIFIED,
     1 1H(,F8.2,1H))
      RETURN
      END
C
C         SUBROUTINE TO CALCULATE DEPTH OF FROST PENETRATION AND
C         CALCULATE HEAVE.(SIMPLIFIED KONRAD MODEL)
C
        SUBROUTINE HEAVE(DTOUT,HVT)
        COMMON /BLOCK/I,J,K,N,DT,D,NWS,DTK1,DF
        COMMON /BLK1/T(12,12,30),ID(160),NTYPE(12,12),N(12)
        COMMON /BLK2/DEN(12,12),WC(12,12),SPHT(12,12),COND(12,12)
        COMMON /BLK5/X(12,12),Z(12,12),DTTMIN(12,12)
        IF (DTK1.LT.100.) RETURN
        IF (T(6,4,K).GT.32.0) RETURN
C
C  CALCUTLATE FROST PENETRATION
C
        DO 555 NX=5,12
        IF (T(6,NX,K).GT.31.0) GO TO 444
```

```
  555 CONTINUE
  444 T1=T(6,(NX-1),K)
      T2=T(6,(NX),K)
      X1=Z(6,(NX-1))/2
      X2=Z(6,(NX))/2+Z(6,(NX-1))
      XP=X1-((((X1-X2)/(T1-T2)))*(T1-32.0))
      NX2=NX-2
      DO 445 NP=2,NX2
      XP=XP+Z(6,NP)
  445 CONTINUE
      XPM=XP*304.8
      XP=XP*12.0
      WRITE (6,447) XP,XPM
  447 FORMAT(//10X,21HFROST PENETRATION =  ,F8.2,5H IN =,F8.2,3H MM)
C
C     CALCULATE SEGREGATIONAL HEAVE
C
      IF (T(6,NWS,K).GT.32.0) GO TO 900
      IF (WC(6,3).GT.0.0) GO TO 480
      IF (NX.GT.5) GO TO 480 .
      GRADT=2*((T(6,5,K)-T(6,4,K))/(Z(6,5)+Z(6,4)))
      GO TO 111
  480 TH1=T(6,(NX-1),K)
      TH2=T(6,(NX-2),K)
      ZH1=Z(6,(NX-1))/2
      ZH2=Z(6,(NX-2))/2
      GRADT=(TH1-TH2)/(ZH1+ZH2)
      IF (WC(6,8).GT.0.0) GO TO 111
      IF (NX.GT.8) GO TO 111
      TH1=T(6,8,K)
      TH2=T(6,7,K)
      GRADT=2*(TH1-TH2)/(Z(6,8)+Z(6,7))
  111 GRADT=GRADT*0.5556/304.8
      SP=1.E-03
      V=SP*GRADT
      HV=1.09*V*DTOUT*3600
      HVS=HV+HVS
      WRITE(6,333) HVS
  333 FORMAT(//10X,27HTOTAL SEGREGATIONAL HEAVE= ,F8.2,3H MM)
C
C   CALCULATE INSITU HEAVE
C
  434 VOID=2.65*WC(6,8)/100.
      POR=VOID/(VOID+1)
      XS=(XP/12.0)-DF
      HVI=0.09*0.90*POR*XS
      HVI=HVI*304.8
      HVT=HVI+HVS
      WRITE(6,223) HVT
  223 FORMAT(//10X,27HTOTAL HEAVE=               ,F8.2,3H MM)
  900 RETURN
      END
```

INPUT FOR THE TWO DIMENSIONAL HEAT FLOW MODEL

```
 1     144   12   12   12   12   12   12   12   12   12   12   12   12   12
 2       1    1    5      6.01     120.0     145.0      1.01
 3       2    1    2      6.0      120.0      82.1     30.0
 4       3    1    2      2.0      120.0      82.1     30.0
 5       4    1    2      6.0      121.0      82.1     30.0
 6       5    1    2     12.0      120.0      82.1     30.0
 7       6    1    2      6.0      120.0      82.1     30.0
 8       7    1    2      6.0      120.0      82.1     30.0
 9       8    1    2     12.0      120.0      82.1     30.0
10       9    1    2     12.0      120.0      82.1     30.0
11      10    1    2     24.0      120.0      82.1     30.0
12      11    1    2     36.0      120.0      82.1     30.0
13      12    1    5    200.0      120.0      82.1     30.0
14       1    2    4      6.01      72.0     145.0      1.01
15       2    2    1      6.0       72.0      82.1     30.0
16       3    2    1      2.0       72.0      82.1     30.0
17       4    2    1      6.0       72.0      82.1     30.0
18       5    2    1     12.0       72.0      82.1     30.0
19       6    2    1      6.0       72.0      82.1     30.0
20       7    2    1      6.0       72.0      82.1     30.0
21       8    2    1     12.0       72.0      82.1     30.0
22       9    2    1     12.0       72.0      82.1     30.0
23      10    2    1     24.0       72.0      82.1     30.0
24      11    2    1     36.0       72.0      82.1     30.0
25      12    2    5    200.0       72.0      82.1     30.0
26       1    3    4      6.01       6.0     145.0      1.01
27       2    3    1      6.0        6.0      82.1     30.0
28       3    3    1      2.0        6.0      82.1     30.0
29       4    3    1      6.0        6.0      82.1     30.0
30       5    3    1     12.0        6.0      82.1     30.0
31       6    3    1      6.0        6.0      82.1     30.0
32       7    3    1      6.0        6.0      82.1     30.0
33       8    3    1     12.0        6.0      82.1     30.0
34       9    3    1     12.0        6.0      82.1     30.0
35      10    3    1     24.0        6.0      82.1     30.0
36      11    3    1     36.0        6.0      82.1     30.0
37      12    3    5    200.0        6.0      82.1     30.0
38       1    4    4      6.01      12.0     145.0      1.01
39       2    4    1      6.0       12.0      82.1     30.0
40       3    4    1      2.0       12.0       1.0      0.0
41       4    4    1      6.0       12.0      82.1     30.0
42       5    4    1     12.0       12.0      82.1     30.0
43       6    4    1      6.0       12.0      82.1     30.0
44       7    4    1      6.0       12.0      82.1     30.0
45       8    4    1     12.0       12.0      82.1     30.0
46       9    4    1     12.0       12.0      82.1     30.0
47      10    4    1     24.0       12.0      82.1     30.0
48      11    4    1     36.0       12.0      82.1     30.0
49      12    4    5    200.0       12.0      82.1     30.0
50       1    5    4      6.01      22.0     145.0      1.01
51       2    5    1      6.0       22.0       1.0      0.0
52       3    5    1      2.0       22.0       1.0      0.0
53       4    5    1      6.0       22.0      82.1     30.0
54       5    5    1     12.0       22.0      82.1     30.0
55       6    5    1      6.0       22.0      82.1     30.0
56       7    5    1      6.0       22.0      82.1     30.0
57       8    5    1     12.0       22.0      82.1     30.0
58       9    5    1     12.0       22.0      82.1     30.0
59      10    5    1     24.0       22.0      82.1     30.0
60      11    5    1     36.0       22.0      82.1     30.0
61      12    5    5    200.0       22.0      82.1     30.0
62       1    6    4      6.01       4.0     145.0      1.01
63       2    6    1      6.0        4.0       1.0      0.0
64       3    6    1      2.0        4.0       1.0      0.0
65       4    6    1      6.0        4.0      82.1     30.0
66       5    6    1     12.0        4.0      82.1     30.0
67       6    6    1      6.0        4.0      82.1     30.0
68       7    6    1      6.0        4.0      82.1     30.0
69       8    6    1     12.0        4.0      82.1     30.0
70       9    6    1     12.0        4.0      82.1     30.0
71      10    6    1     24.0        4.0      82.1     30.0
72      11    6    1     36.0        4.0      82.1     30.0
73      12    6    5    200.0        4.0      82.1     30.0
74       1    7    4      4.01      22.0       1.0      0.0
75       2    7    1      6.0       22.0       1.0      0.0
76       3    7    1      2.0       22.0       1.0      0.0
77       4    7    1      6.0       22.0      82.1     30.0
78       5    7    1     12.0       22.0      82.1     30.0
79       6    7    1      6.0       22.0      82.1     30.0
80       7    7    1      6.0       22.0      82.1     30.0
81       8    7    1     12.0       22.0      82.1     30.0
82       9    7    1     12.0       22.0      82.1     30.0
83      10    7    1     24.0       22.0      82.1     30.0
84      11    7    1     36.0       22.0      82.1     30.0
85      12    7    5    200.0       22.0      82.1     30.0
86       1    8    4      4.01      12.0    1.0        0.0
87       2    8    1      6.0       12.0      82.1     30.0
88       3    8    1      2.0       12.0       1.0      0.0
89       4    8    1      6.0       12.0      82.1     30.0
90       5    8    1     12.0       12.0      82.1     30.0
91       6    8    1      6.0       12.0      82.1     30.0
92       7    8    1      6.0       12.0      82.1     30.0
93       8    8    1     12.0       12.0      82.1     30.0
94       9    8    1     12.0       12.0      82.1     30.0
```

95	10	8	1	24.0	12.0	92.1	30.0
96	11	8	1	36.0	12.0	92.1	30.0
97	12	8	8	200.0	12.0	92.1	30.0
98	1	9	4	4.01	6.0	1.0	0.0
99	2	9	1	6.0	6.0	92.1	30.0
100	3	9	1	2.0	6.0	92.1	30.0
101	4	9	1	6.0	6.0	92.1	30.0
102	5	9	1	6.0	6.0	92.1	30.0
103	6	9	1	6.0	6.0	92.1	30.0
104	7	9	1	6.0	6.0	92.1	30.0
105	8	9	1	6.0	6.0	92.1	30.0
106	9	9	1	6.0	6.0	92.1	30.0
107	10	9	1	24.0	6.0	92.1	30.0
108	11	9	1	36.0	6.0	92.1	30.0
109	12	9	8	200.0	6.0	92.1	30.0
110	1	10	4	4.01	36.0	1.0	0.0
111	2	10	1	6.0	36.0	92.1	30.0
112	3	10	1	2.0	36.0	92.1	30.0
113	4	10	1	6.0	36.0	92.1	30.0
114	5	10	1	12.0	36.0	92.1	30.0
115	6	10	1	6.0	36.0	92.1	30.0
116	7	10	1	6.0	36.0	92.1	30.0
117	8	10	1	12.0	36.0	92.1	30.0
118	9	10	1	12.0	36.0	92.1	30.0
119	10	10	1	24.0	36.0	92.1	30.0
120	11	10	1	36.0	36.0	92.1	30.0
121	12	10	8	200.0	36.0	92.1	30.0
122	1	11	4	4.01	72.0	1.0	0.0
123	2	11	1	6.0	72.0	92.1	30.0
124	3	11	1	2.0	72.0	92.1	30.0
125	4	11	1	6.0	72.0	92.1	30.0
126	5	11	1	12.0	72.0	92.1	30.0
127	6	11	1	6.0	72.0	92.1	30.0
128	7	11	1	6.0	72.0	92.1	30.0
129	8	11	1	12.0	72.0	92.1	30.0
130	9	11	1	12.0	72.0	92.1	30.0
131	10	11	1	24.0	72.0	92.1	30.0
132	11	11	1	36.0	72.0	92.1	30.0
133	12	11	8	200.0	72.0	92.1	30.0
134	1	12	6	4.01	120.0	1.0	0.0
135	2	12	3	6.0	120.0	92.1	30.0
136	3	12	3	2.0	120.0	92.1	30.0
137	4	12	3	6.0	120.0	92.1	30.0
138	5	12	3	12.0	120.0	92.1	30.0
139	6	12	3	6.0	120.0	92.1	30.0
140	7	12	3	6.0	120.0	92.1	30.0
141	8	12	3	12.0	120.0	92.1	30.0
142	9	12	3	12.0	120.0	92.1	30.0
143	10	12	3	24.0	120.0	92.1	30.0
144	11	12	3	36.0	120.0	92.1	30.0
145	12	12	10	200.0	120.0	92.1	30.0
146	1	1	0.000	25.40	0.000	2.0000	
147	2	1	0.000	16.56	0.000	1.100	
148	3	1	0.000	16.56	0.000	1.100	
149	4	1	0.000	16.56	0.000	1.100	
150	5	1	0.000	16.56	0.000	1.100	
151	6	1	0.000	16.56	0.000	1.100	
152	7	1	0.000	16.56	0.000	1.100	
153	8	1	0.000	16.56	0.000	1.100	
154	9	1	0.000	16.56	0.000	1.100	
155	10	1	0.000	16.56	0.000	1.100	
156	11	1	0.000	16.56	0.000	1.100	
157	12	1	0.000	16.56	0.000	1.100	
158	1	2	0.000	25.40	0.000	2.0000	
159	2	2	0.000	16.56	0.000	1.100	
160	3	2	0.000	16.56	0.000	1.100	
161	4	2	0.000	16.56	0.000	1.100	
162	5	2	0.000	16.56	0.000	1.100	
163	6	2	0.000	16.56	0.000	1.100	
164	7	2	0.000	16.56	0.000	1.100	
165	8	2	0.000	16.56	0.000	1.100	
166	9	2	0.000	16.56	0.000	1.100	
167	10	2	0.000	16.56	0.000	1.100	
168	11	2	0.000	16.56	0.000	1.100	
169	12	2	0.000	16.56	0.000	1.100	
170	1	3	0.000	25.40	0.000	2.0000	
171	2	3	0.000	16.56	0.000	1.100	
172	3	3	0.000	16.56	0.000	1.100	
173	4	3	0.000	16.56	0.000	1.100	
174	5	3	0.000	16.56	0.000	1.100	
175	6	3	0.000	16.56	0.000	1.100	
176	7	3	0.000	16.56	0.000	1.100	
177	8	3	0.000	16.56	0.000	1.100	
178	9	3	0.000	16.56	0.000	1.100	
179	10	3	0.000	16.56	0.000	1.100	
180	11	3	0.000	16.56	0.000	1.100	
181	12	3	0.000	16.56	0.000	1.100	
182	1	4	0.000	25.40	0.000	2.0000	
183	2	4	0.000	16.56	0.000	1.100	
184	3	4	0.000	0.874	0.000	0.025	
185	4	4	0.000	16.56	0.000	1.100	
186	5	4	0.000	16.56	0.000	1.100	
187	6	4	0.000	16.56	0.000	1.100	
188	7	4	0.000	16.56	0.000	1.100	

```
189      8   4   0.000   15.88   0.000    1.100
190      9   4   0.000   15.88   0.000    1.100
191     10   4   0.000   15.88   0.000    1.100
192     11   4   0.000   15.88   0.000    1.100
193     12   4   0.000   15.88   0.000    1.100
194      1   5   0.000   25.40   0.000    2.0000
195      2   5   0.000   0.874   0.000   0.024
196      3   5   0.000   32.48   0.000    0.981
197      4   5   0.000   15.88   0.000    1.100
198      5   5   0.000   15.88   0.000    1.100
199      6   5   0.000   15.88   0.000    1.100
200      7   5   0.000   15.88   0.000    1.100
201      8   5   0.000   15.88   0.000    1.100
202      9   5   0.000   15.88   0.000    1.100
203     10   5   0.000   15.88   0.000    1.100
204     11   5   0.000   15.88   0.000    1.100
205     12   5   0.000   15.88   0.000    1.100
206      1   6   0.000   25.40   0.000    2.0000
207      2   6   0.000   0.874   0.000   0.024
208      3   6   0.000   32.48   0.000    0.981
209      4   6   0.000   15.88   0.000    1.100
210      5   6   0.000   15.88   0.000    1.100
211      6   6   0.000   15.88   0.000    1.100
212      7   6   0.000   15.88   0.000    1.100
213      8   6   0.000   15.88   0.000    1.100
214      9   6   0.000   15.88   0.000    1.100
215     10   6   0.000   15.88   0.000    1.100
216     11   6   0.000   15.88   0.000    1.100
217     12   6   0.000   15.88   0.000    1.100
218      1   7   0.000    5.90   0.000   0.15000
219      2   7   0.000   0.874   0.000    0.024
220      3   7   0.000   32.48   0.000    0.981
221      4   7   0.000   15.88   0.000    1.100
222      5   7   0.000   15.88   0.000    1.100
223      6   7   0.000   15.88   0.000    1.100
224      7   7   0.000   15.88   0.000    1.100
225      8   7   0.000   15.88   0.000    1.100
226      9   7   0.000   15.88   0.000    1.100
227     10   7   0.000   15.88   0.000    1.100
228     11   7   0.000   15.88   0.000    1.100
229     12   7   0.000   15.88   0.000    1.100
230      1   8   0.000    5.90   0.000   0.1500
231      2   8   0.000   15.88   0.000    1.100
232      3   8   0.000   0.874   0.000    0.024
233      4   8   0.000   15.88   0.000    1.100
234      5   8   0.000   15.88   0.000    1.100
235      6   8   0.000   15.88   0.000    1.100
236      7   8   0.000   15.88   0.000    1.100
237      8   8   0.000   15.88   0.000    1.100
238      9   8   0.000   15.88   0.000    1.100
239     10   8   0.000   15.88   0.000    1.100
240     11   8   0.000   15.88   0.000    1.100
241     12   8   0.000   15.88   0.000    1.100
242      1   9   0.000    5.90   0.000   0.1500
243      2   9   0.000   15.88   0.000    1.100
244      3   9   0.000   15.88   0.000    1.100
245      4   9   0.000   15.88   0.000    1.100
246      5   9   0.000   15.88   0.000    1.100
247      6   9   0.000   15.88   0.000    1.100
248      7   9   0.000   15.88   0.000    1.100
249      8   9   0.000   15.88   0.000    1.100
250      9   9   0.000   15.88   0.000    1.100
251     10   9   0.000   15.88   0.000    1.100
252     11   9   0.000   15.88   0.000    1.100
253     12   9   0.000   15.88   0.000    1.100
254      1  10   0.000    5.90   0.000   0.1500
255      2  10   0.000   15.88   0.000    1.100
256      3  10   0.000   15.88   0.000    1.100
257      4  10   0.000   15.88   0.000    1.100
258      5  10   0.000   15.88   0.000    1.100
259      6  10   0.000   15.88   0.000    1.100
260      7  10   0.000   15.88   0.000    1.100
261      8  10   0.000   15.88   0.000    1.100
262      9  10   0.000   15.88   0.000    1.100
263     10  10   0.000   15.88   0.000    1.100
264     11  10   0.000   15.88   0.000    1.100
265     12  10   0.000   15.88   0.000    1.100
266      1  11   0.000    5.90   0.000   0.1500
267      2  11   0.000   15.88   0.000    1.100
268      3  11   0.000   15.88   0.000    1.100
269      4  11   0.000   15.88   0.000    1.100
270      5  11   0.000   15.88   0.000    1.100
271      6  11   0.000   15.88   0.000    1.100
272      7  11   0.000   15.88   0.000    1.100
273      8  11   0.000   15.88   0.000    1.100
274      9  11   0.000   15.88   0.000    1.100
275     10  11   0.000   15.88   0.000    1.100
276     11  11   0.000   15.88   0.000    1.100
277     12  11   0.000   15.88   0.000    1.100
278      1  12   0.000    5.90   0.000   0.1500
279      2  12   0.000   15.88   0.000    1.100
280      3  12   0.000   15.88   0.000    1.100
281      4  12   0.000   15.88   0.000    1.100
282      5  12   0.000   15.88   0.000    1.100
283      6  12   0.000   15.88   0.000    1.100
284      7  12   0.000   15.88   0.000    1.100
285      8  12   0.000   15.88   0.000    1.100
```

```
286          9    12    0.000     18.58     0.000     1.100
287         10    12    0.000     18.58     0.000     1.100
288         11    12    0.000     18.58     0.000     1.100
289         12    12    0.000     18.58     0.000     1.100
290          1     1    1
291            100.      0.770    -20.03
292          2     1    1
293            100.      0.770    -20.03
294          3     1    1
295            100.      0.770    -20.03
296          4     1    1
297            100.      0.770    -20.03
298          5     1    1
299            100.      0.770    -20.03
300          6     1    1
301            100.      0.770    -20.03
302          7     1    1
303            100.      0.770    -20.03
304          8     1    1
305            100.      0.770    -20.03
306          9     1    1
307            100.      0.770    -20.03
308         10     1    1
309            100.      0.770    -20.03
310         11     1    1
311            100.      0.770    -20.03
312         12     1    1
313            100.      0.770    -20.03
314          1     2    1
315            100.      0.770    -20.03
316          2     2    1
317            100.      0.770    -20.03
318          3     2    1
319            100.      0.770    -20.03
320          4     2    1
321            100.      0.770    -20.03
322          5     2    1
323            100.      0.770    -20.03
324          6     2    1
325            100.      0.770    -20.03
326          7     2    1
327            100.      0.770    -20.03
328          8     2    1
329            100.      0.770    -20.03
330          9     2    1
331            100.      0.770    -20.03
332         10     2    1
333            100.      0.770    -20.03
334         11     2    1
335            100.      0.770    -20.03
336         12     2    1
337            100.      0.770    -20.03
338          1     3    1
339            100.      0.770    -20.03
340          2     3    1
341            100.      0.770    -20.03
342          3     3    1
343            100.      0.770    -20.03
344          4     3    1
345            100.      0.770    -20.03
346          5     3    1
347            100.      0.770    -20.03
348          6     3    1
349            100.      0.770    -20.03
350          7     3    1
351            100.      0.770    -20.03
352          8     3    1
353            100.      0.770    -20.03
354          9     3    1
355            100.      0.770    -20.03
356         10     3    1
357            100.      0.770    -20.03
358         11     3    1
359            100.      0.770    -20.03
360         12     3    1
361            100.      0.770    -20.03
362          1     4    1
363            100.      0.770    -20.03
364          2     4    1
365            100.      0.770    -20.03
366          3     4    1
367            100.      0.770    -20.03
368          4     4    1
369            100.      0.770    -20.03
370          5     4    1
371            100.      0.770    -20.03
372          6     4    1
373            100.      0.770    -20.03
374          7     4    1
375            100.      0.770    -20.03
376          8     4    1
377            100.      0.770    -20.03
378          9     4    1
379            100.      0.770    -20.03
```

```
380        10     4     1
381             100.      0.770     -20.03
382        11     4     1
383             100.      0.770     -20.03
384        12     4     1
385             100.      0.770     -20.03
386         1     5     1
387             100.      0.770     -20.03
388         2     5     1
389             100.      0.770     -20.03
390         3     5     1
391             100.      0.770     -20.03
392         4     5     1
393             100.      0.770     -20.03
394         5     5     1
395             100.      0.770     -20.03
396         6     5     1
397             100.      0.770     -20.03
398         7     5     1
399             100.      0.770     -20.03
400         8     5     1
401             100.      0.770     -20.03
402         9     5     1
403             100.      0.770     -20.03
404        10     5     1
405             100.      0.770     -20.03
406        11     5     1
407             100       0.770     -20.03
408        12     5     1
409             100.      0.770     -20.03
410         1     6     1
411             100.      0.770     -20.03
412         2     6     1
413             100.      0.770     -20.03
414         3     6     1
415             100.      0.770     -20.03
416         4     6     1
417             100.      0.770     -20.03
418         5     6     1
419             100.      0.770     -20.03
420         6     6     1
421             100.      0.770     -20.03
422         7     6     1
423             100.      0.770     -20.03
424         8     6     1
425             100.      0.770     -20.03
426         9     6     1
427             100.      0.770     -20.03
428        10     6     1
429             100.      0.770     -20.03
430        11     6     1
431             100.      0.770     -20.03
432        12     6     1
433             100.      0.770     -20.03
434         1     7     1
435             100.      0.770     -20.03
436         2     7     1
437             100.      0.770     -20.03
438         3     7     1
439             100.      0.770     -20.03
440         4     7     1
441             100.      0.770     -20.03
442         5     7     1
443             100.      0.770     -20.03
444         6     7     1
445             100.      0.770     -20.03
446         7     7     1
447             100.      0.770     -20.03
448         8     7     1
449             100.      0.770     -20.03
450         9     7     1
451             100.      0.770     -20.03
452        10     7     1
453             100.      0.770     -20.03
454        11     7     1
455             100.      0.770     -20.03
456        12     7     1
457             100.      0.770     -20.03
458        12     8     1
459             100.      0.770     -20.03
460         1     8     1
461             100.      0.770     -20.03
462         2     8     1
463             100.      0.770     -20.03
464         3     8     1
465             100.      0.770     -20.03
466         4     8     1
467             100.      0.770     -20.03
468         5     8     1
469             100.      0.770     -20.03
470         6     8     1
471             100.      0.770     -20.03
472         7     8     1
473             100.      0.770     -20.03
```

```
474          8    8     1
475             100.     0.770     -20.03
476          9    8     1
477             100.     0.770     -20.03
478         10    8     1
479             100.     0.770     -20.03
480         11    8     1
481             100.     0.770     -20.03
482          1    9     1
483             100.     0.770     -20.03
484         12    9     1
485             100.     0.770     -20.03
486          2    9     1
487             100.     0.770     -20.03
488          3    9     1
489             100.     0.770     -20.03
490          4    9     1
491             100.     0.770     -20.03
492          5    9     1
493             100.     0.770     -20.03
494          6    9     1
495             100.     0.770     -20.03
496          7    9     1
497             100.     0.770     -20.03
498          8    9     1
499             100.     0.770     -20.03
500          9    9     1
501             100.     0.770     -20.03
502         10    9     1
503             100.     0.770     -20.03
504         11    9     1
505             100.     0.770     -20.03
506          1   10     1
507             100.     0.770     -20.03
508         12   10     1
509             100.     0.770     -20.03
510          2   10     1
511             100.     0.770     -20.03
512          3   10     1
513             100.     0.770     -20.03
514          4   10     1
515             100.     0.770     -20.03
516          5   10     1
517             100.     0.770     -20.03
518          6   10     1
519             100.     0.770     -20.03
520          7   10     1
521             100.     0.770     -20.03
522          8   10     1
523             100.     0.770     -20.03
524          9   10     1
525             100.     0.770     -20.03
526         10   10     1
527             100.     0.770     -20.03
528         11   10     1
529             100.     0.770     -20.03
530          1   11     1
531             100.     0.770     -20.03
532         12   11     1
533             100.     0.770     -20.03
534          2   11     1
535             100.     0.770     -20.03
536          3   11     1
537             100.     0.770     -20.03
538          4   11     1
539             100.     0.770     -20.03
540          5   11     1
541             100.     0.770     -20.03
542          6   11     1
543             100.     0.770     -20.03
544          7   11     1
545             100.     0.770     -20.03
546          8   11     1
547             100.     0.770     -20.03
548          9   11     1
549             100.     0.770     -20.03
550         10   11     1
551             100.     0.770     -20.03
552         11   11     1
553             100.     0.770     -20.03
554          1   12     1
555             100.     0.770     -20.03
556         12   12     1
557             100.     0.770     -20.03
558          2   12     1
559             100.     0.770     -20.03
560          3   12     1
561             100.     0.770     -20.03
562          4   12     1
563             100.     0.770     -20.03
564          5   12     1
565             100.     0.770     -20.03
566          6   12     1
567             100.     0.770     -20.03
568          7   12     1
569             100.     0.770     -20.03
570          8   12     1
```

```
571          100.      0.770     -20.03
572        9   12    1
573          100.      0.770     -20.03
574       10   12    1
575          100.      0.770     -20.03
576       11   12    1
577          100.      0.770     -20.03
578        2
579     33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8
580     34.5   34.5   34.5   34.5   34.5   34.5   34.5   34.5   34.5   34.5   34.5   34.5
581     35.8   35.8   35.8   35.8   35.8   35.8   35.8   35.8   35.8   35.8   35.8   35.8
582     36.5   36.5   36.5   36.5   36.5   36.5   36.5   36.5   36.5   36.5   36.5   36.5
583     38.4   38.4   38.4   38.4   38.4   38.4   38.4   38.4   38.4   38.4   38.4   38.4
584     40.4   40.4   40.4   40.4   40.4   40.4   40.4   40.4   40.4   40.4   40.4   40.4
585     41.3   41.3   41.3   41.3   41.3   41.3   41.3   41.3   41.3   41.3   41.3   41.3
586     43.2   43.2   43.2   43.2   43.2   43.2   43.2   43.2   43.2   43.2   43.2   43.2
587     45.7   45.7   45.7   45.7   45.7   45.7   45.7   45.7   45.7   45.7   45.7   45.7
588     46.1   46.1   46.1   46.1   46.1   46.1   46.1   46.1   46.1   46.1   46.1   46.1
589     45.2   45.2   45.2   45.2   45.2   45.2   45.2   45.2   45.2   45.2   45.2   45.2
590     41.9   41.9   41.9   41.9   41.9   41.9   41.9   41.9   41.9   41.9   41.9   41.9
591     33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8   33.8
592     38.0   38.0   38.0   38.0   38.0   38.0   38.0   38.0   38.0   38.0   38.0   38.0
593       3800.0        2.00      100.0          0.0       1.0      5
594       72
595        1     1     0.1
596        1     2     0.1
597        1     3     0.1
598        1     4     0.1
599        1     5     0.1
600        1     6     0.1
601        1     7     0.1
602        1     8     0.1
603        1     9     0.1
604        1    10     0.1
605        1    11     0.1
606        1    12     0.1
607        2     1     0.20
608        2     2     0.20
609        2     3     0.20
610        2     4     0.20
611        2     5     0.20
612        2     6     0.20
613        2     7     0.20
614        2     8     0.20
615        2     9     0.20
616        2    10     0.20
617        2    11     0.20
618        2    12     0.20
619        3     1     0.05
620        3     2     0.05
621        3     3     0.05
622        3     4     0.05
623        3     5     0.05
624        3     6     0.05
625        3     7     0.05
626        3     8     0.05
627        3     9     0.05
628        3    10     0.05
629        3    11     0.05
630        3    12     0.05
631        4     1     0.50
632        4     2     0.50
633        4     3     0.50
634        4     4     0.50
635        4     5     0.50
636        4     6     0.50
637        4     7     0.50
638        4     8     0.50
639        4     9     0.50
640        4    10     0.50
641        4    11     0.50
642        4    12     0.50
643        5     1     0.50
644        5     2     0.50
645        5     3     0.50
646        5     4     0.50
647        5     5     0.50
648        5     6     0.50
649        5     7     0.50
650        5     8     0.50
651        5     9     0.50
652        5    10     0.50
653        5    11     0.50
654        5    12     0.50
655        6     1     0.25
656        6     2     0.25
657        6     3     0.25
658        6     4     0.25
659        6     5     0.25
660        6     6     0.25
661        6     7     0.25
662        6     8     0.25
663        6     9     0.25
664        6    10     0.25
```

```
005        8   11    0.25
006        8   12    0.25
007        2
008          16.80   0.000      1.000      0.000      3800.0
009       0.5   0.5   0.5   0.5   0.5   0.5   1.0   1.0   1.0   1.0   1.0   1.0
```

OUTPUT FROM THE TWO DIMENSIONAL HEAT FLOW MODEL

```
                           WIDTH(X), THICKNESS(Z), IN INCHES, AND TYPE OF THE CELL

Z(J)/X(I)          1       2      3      4       5      6      7      8      9     10      11      12
         WIDTH   120.00  72.00  8.00  12.00  22.00   4.00  22.00  12.00  8.00  28.00   72.00  120.00
     THICKNESS

    1     0.010    5      4      4      4      4      4      4      4      4      4      4      6
    2     6.000    2      1      1      1      1      1      1      1      1      1      1      3
    3     2.000    2      1      1      1      1      1      1      1      1      1      1      3
    4     6.000    2      1      1      1      1      1      1      1      1      1      1      3
    5    12.000    2      1      1      1      1      1      1      1      1      1      1      3
    6     6.000    2      1      1      1      1      1      1      1      1      1      1      3
    7     6.000    2      1      1      1      1      1      1      1      1      1      1      3
    8    12.000    2      1      1      1      1      1      1      1      1      1      1      3
    9    12.000    2      1      1      1      1      1      1      1      1      1      1      3
   10    24.000    2      1      1      1      1      1      1      1      1      1      1      3
   11    36.000    2      1      1      1      1      1      1      1      1      1      1      3
   12   300.000    9      8      8      8      8      8      8      8      8      8      8     10


                          UNIT WEIGHT (PCF) AND WATER CONTENT (PERCENT) AT VARIOUS CELLS

Z(J)/X(I)          1      2      3      4      5      6      7      8      9     10     11     12

    1           145.00 145.00 145.00 145.00 145.00 145.00  1.00   1.00   1.00   1.00   1.00   1.00
                  1.01   1.01   1.01   1.01   1.01   1.01  0.0    0.0    0.0    0.0    0.0    0.0

    2            92.10  92.10  92.10  92.10   1.00   1.00   1.00  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  0.0    0.0    0.0    30.00  30.00  30.00  30.00  30.00

    3            92.10  92.10  92.10   1.00   1.00   1.00   1.00   1.00  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  0.0    0.0    0.0    0.0    0.0    30.00  30.00  30.00  30.00

    4            92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00

    5            92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00

    6            92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00

    8            92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00

    9            92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00

   10            92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00

   11            92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00

   12            92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10  92.10
                 30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00  30.00


  CELL(Z,X)            VOLUMETRIC HEAT                    CONDUCTIVITY
                        (BTU/CU FT/F)                   (BTU/FT/HOUR/F)


     1, 1           C=   0.0   T + 25.400           K =   0.0    T +  2.000
     1, 2           C=   0.0   T + 25.400           K =   0.0    T +  2.000
     1, 3           C=   0.0   T + 25.400           K =   0.0    T +  2.000
     1, 4           C=   0.0   T + 25.400           K =   0.0    T +  2.000
     1, 5           C=   0.0   T + 25.400           K =   0.0    T +  2.000
     1, 6           C=   0.0   T + 25.400           K =   0.0    T +  2.000
     1, 7           C=   0.0   T +  5.000           K =   0.0    T +  0.150
     1, 8           C=   0.0   T +  5.000           K =   0.0    T +  0.150
     1, 9           C=   0.0   T +  5.000           K =   0.0    T +  0.150
     1,10           C=   0.0   T +  5.000           K =   0.0    T +  0.150
     1,11           C=   0.0   T +  5.000           K =   0.0    T +  0.150
     1,12           C=   0.0   T +  5.000           K =   0.0    T +  0.150
```

```
 2, 1      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 2, 2      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 2, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 2, 4      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 2, 5      C=   0.0   T = 22.480          K =  0.0    T =  0.889
 2, 6      C=   0.0   T = 22.480          K =  0.0    T =  0.889
 2, 7      C=   0.0   T = 22.480          K =  0.0    T =  0.889
 2, 8      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 2, 9      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 2,10      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 2,11      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 2,12      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 3, 1      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 3, 2      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 3, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 3, 4      C=   0.0   T =  0.874          K =  0.0    T =  0.024
 3, 5      C=   0.0   T =  0.874          K =  0.0    T =  0.024
 3, 6      C=   0.0   T =  0.874          K =  0.0    T =  0.024
 3, 7      C=   0.0   T =  0.874          K =  0.0    T =  0.020
 3, 8      C=   0.0   T =  0.874          K =  0.0    T =  0.020
 3, 9      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 3,10      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4, 2      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4, 4      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4, 5      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4, 6      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4, 7      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4, 8      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4, 9      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4,10      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4,11      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 4,12      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 1      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 2      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 4      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 5      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 6      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 7      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 8      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5, 9      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5,10      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5,11      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 5,12      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 1      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 2      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 4      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 5      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 6      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 7      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 8      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6, 9      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6,10      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6,11      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 6,12      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 1      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 2      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 4      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 5      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 6      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 7      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 8      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7, 9      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7,10      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7,11      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 7,12      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 1      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 2      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 4      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 5      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 6      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 7      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 8      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8, 9      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8,10      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 8,11      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9, 4      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9, 5      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9, 6      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9, 7      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9, 8      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9, 9      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9,10      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9,11      C=   0.0   T = 18.580          K =  0.0    T =  1.100
 9,12      C=   0.0   T = 18.580          K =  0.0    T =  1.100
10, 1      C=   0.0   T = 18.580          K =  0.0    T =  1.100
10, 2      C=   0.0   T = 18.580          K =  0.0    T =  1.100
10, 3      C=   0.0   T = 18.580          K =  0.0    T =  1.100
10, 4      C=   0.0   T = 18.580          K =  0.0    T =  1.100
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 10, 5           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 10, 6           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 10, 7           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 10, 8           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 10, 9           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 10,10           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 10,11           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 10,12           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 1           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 2           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 3           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 4           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 5           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 6           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 7           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 8           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11, 9           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11,10           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11,11           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 11,12           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 1           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 2           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 3           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 4           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 5           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 6           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 7           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 8           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12, 9           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12,10           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12,11           C=   0.0  T + 16.580          K =  0.0   T +  1.100
 12,12           C=   0.0  T + 16.580          K =  0.0   T +  1.100


CELL(I,K)           ICEFORMATION CURVE IN, EXPONENTIAL FUNCTION

    1, 1        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    1, 2        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    1, 3        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    1, 4        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    1, 5        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    1, 9        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    1,10        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    1,11        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    1,12        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 1        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 2        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 3        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 4        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 5        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 6        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 7        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 8        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2, 9        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2,10        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2,11        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    2,12        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 1        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 2        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 3        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 4        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 5        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 6        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 7        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 8        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3, 9        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3,10        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3,11        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    3,12        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 1        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 2        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 3        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 4        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 5        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 6        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 7        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 8        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4, 9        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4,10        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4,11        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    4,12        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5, 1        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K)*+, -20.030 )
    5, 2        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5, 3        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5, 4        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5, 5        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5, 6        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5, 7        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5, 8        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5, 9        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5,10        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5,11        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    5,12        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
    6, 1        PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -20.030 )
 6, 2          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 6, 3          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 6, 4          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 6, 8          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 6, 9          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 6,10          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 6,11          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 6,12          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 1          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 2          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 3          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 4          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 5          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 6          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 7          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 8          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7, 9          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7,10          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7,11          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 7,12          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 1          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 2          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 3          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 4          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 5          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 6          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 7          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 8          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8, 9          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8,10          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8,11          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 8,12          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 1          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 2          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 3          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 4          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 5          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 6          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 7          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 8          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9, 9          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9,10          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9,11          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
 9,12          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 1          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 2          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 3          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 4          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 5          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 6          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 7          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 8          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10, 9          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10,10          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10,11          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
10,12          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11, 1          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11, 2          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11, 3          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11, 4          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11, 5          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11, 6          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11, 7          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11,11          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
11,12          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 1          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 2          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 3          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 4          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 5          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 6          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 7          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 8          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12, 9          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12,10          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12,11          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )
12,12          PERCENT WC FROZEN ,100.00 - EXP( 0.770 *T(I,J,K) +, -30.030 )

INITIAL CONDTION/      TEMPERATURES AT CENTERS OF ALL CELLS GIVEN
 33.80 33.80 33.80 33.80 33.80 33.80 33.80 33.80 33.80 33.80 33.80 33.80
 34.80 34.80 34.80 34.80 34.80 34.80 34.80 34.80 34.80 34.80 34.80 34.80
 35.60 35.60 35.60 35.60 35.60 35.60 35.60 35.60 35.60 35.60 35.60 35.60
 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50
 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40
 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40
 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30
 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20
 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70
 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10
 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20
 41.80 41.80 41.80 41.80 41.80 41.80 41.80 41.80 41.80 41.80 41.80 41.80
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INITIAL UPPER BOUNDARY TEMPERATURES
32.80 32.80 32.80 32.80 32.80 32.80 32.80 32.80 32.80 32.80 32.80 32.80

INITIAL LOWER BOUNDARY TEMPERATURES
38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.^0 38.00


DEPTH TO WATER SOURCE, ELEMENT NUMBER THAT HEAVE BEGINS AT IS   ,     5
DEPTH TO FOOTING IS     1.00



INCREMENT OF TIME, DT =  2.000 HOURS, (EXCEPT FOR THOSE CELLS LISTED FOLLOWS, IF ANY)

     J   I    DT
     1   1   0.100
     1   2   0.100
     1   3   0.100
     1   4   0.100
     1   5   0.100
     1   6   0.100
     1   7   0.100
     1  11   0.100
     1  12   0.100
     2   1   0.200
     2   2   0.200
     2   3   0.200
     2   4   0.200
     2   5   0.200
     2   6   0.200
     2   7   0.200
     2   8   0.200
     2   9   0.200
     2  10   0.200
     2  11   0.200
     2  12   0.200
     3   1   0.080
     3   2   0.080
     3   3   0.080
     3   4   0.080
     3   5   0.080
     3   6   0.080
     3   7   0.080
     3   8   0.080
     3   9   0.080
     3  10   0.080
     3  11   0.080
     3  12   0.080
     4   1   0.500
     4   2   0.500
     4   3   0.500
     4   4   0.500
     4   5   0.500
     4   6   0.500
     4   7   0.500
     4   8   0.500
     4   9   0.500
     4  10   0.500
     4  11   0.500
     4  12   0.500
     5   1   0.500
     5   2   0.500
     5   3   0.500
     5   4   0.500
     5   5   0.500
     5   6   0.500
     5   7   0.500
     5   8   0.500
     5   9   0.500
     5  10   0.500
     5  11   0.500
     5  12   0.500
     6   1   0.250
     6   2   0.250
     6   3   0.250
     6   4   0.250
     6   5   0.250
     6   6   0.250
     6   7   0.250
     6   8   0.250
     6  12   0.250

 TOTAL DURATION OF TIME = 3600.0 HOURS = 150 DAYS AND  0 HOURS


BOUNDARY CONDITIONS     T(0,TIME)= 32 -  18.0000 SIN(3.14*T/ 3600.00) +  0.0    COS(3.14*T/ 3600.00)
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CORRECTION FACTOR FOR BOUNDARY VALUES FOR AIR GROUND INTERFACE =,  (I=1,..,12)
 0.50  0.50  0.50  0.50  0.50  0.50  1.00  1.00  1.00  1.00  1.00  1.00

TEMPERATURE AT LOWER BOUNDARY REMAINS CONSTANT A T ALL THE TIME(EQUAL TO INITIAL TEMERATURE), =  39.0
        TIME AT THIS STEP=    0.0   HRS.            AIR TEMPERATURE= 32.00

                    1     2     3     4     5     6     7     8     9     10    11    12
UPPER BOUNDARY    32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00
  LAYER   1       33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00
  LAYER   2       34.50 34.50 34.50 34.50 34.50 34.50 34.50 34.50 34.50 34.50 34.50 34.50 34.50
  LAYER   3       35.50 35.50 35.50 35.50 35.50 35.50 35.50 35.50 35.50 35.50 35.50 35.50 35.50
  LAYER   4       36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50 36.50
  LAYER   5       38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40 38.40
  LAYER   6       40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40 40.40
  LAYER   7       41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30 41.30
  LAYER   8       43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20 43.20
  LAYER   9       45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70 45.70
  LAYER  10       46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10 46.10
  LAYER  11       45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20 45.20
  LAYER  12       41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90
LOWER BOUNDARY    39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP=  100.00  HRS.            AIR TEMPERATURE= 30.36

                    1     2     3     4     5     6     7     8     9     10    11    12
UPPER BOUNDARY    30.53 30.53 30.53 30.53 30.53 30.53 30.36 30.36 30.36 30.36 30.36 30.36
  LAYER   1       31.30 31.30 31.21 31.06 30.96 31.02 31.27 31.74 32.29 32.49 32.49 32.49 32.49
  LAYER   2       32.90 32.81 32.82 31.98 31.61 31.79 32.52 33.42 34.61 35.16 35.16 35.16 35.16
  LAYER   3       34.16 34.16 34.46 34.77 34.83 35.04 35.49 35.90 36.07 35.95 35.95 35.95 35.95
  LAYER   4       35.33 35.35 36.12 37.56 38.19 38.33 38.49 38.17 37.31 36.76 36.72 36.72 36.72
  LAYER   5       37.72 37.74 38.41 38.81 39.20 39.26 39.34 39.10 38.76 38.44 38.40 38.40 38.40
  LAYER   6       38.69 38.71 40.09 40.25 40.45 40.48 40.51 40.36 40.10 40.04 40.02 40.02 40.02
  LAYER   7       40.86 40.87 41.12 41.20 41.32 41.34 41.34 41.24 41.20 41.06 41.06 41.06 41.06
  LAYER   8       42.43 42.42 42.52 42.55 42.58 42.58 42.58 42.48 42.44 42.46 42.46 42.46 42.46
  LAYER   9       43.92 43.93 43.96 43.96 43.97 43.96 43.93 43.75 43.50 43.86 43.84 43.84 43.84
  LAYER  10       45.29 45.29 45.29 45.29 45.29 45.28 45.27 45.21 45.17 45.20 45.20 45.20 45.20
  LAYER  11       45.13 45.13 45.13 45.13 45.13 45.13 45.13 45.12 45.12 45.13 45.13 45.13 45.13
  LAYER  12       41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90 41.90
LOWER BOUNDARY    39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP=  200.00  HRS.            AIR TEMPERATURE= 28.74

                    1     2     3     4     5     6     7     8     9     10    11    12
  LAYER   3       33.13 33.16 33.78 34.56 34.16 34.41 34.95 35.26 35.54 35.48 35.44 35.44 35.44
  LAYER   4       34.27 34.31 35.57 37.32 38.16 38.40 38.62 38.11 37.02 36.36 36.30 36.29 36.29
  LAYER   5       35.70 35.78 36.01 38.59 39.24 39.40 39.50 39.07 38.57 38.14 38.06 38.06 38.06
  LAYER   6       36.71 36.76 39.65 39.93 40.34 40.44 40.49 40.18 39.84 39.64 39.59 39.59 39.59
  LAYER   7       39.90 39.94 40.59 40.77 41.06 41.12 41.16 40.94 40.86 40.58 40.52 40.52 40.52
  LAYER   8       41.45 41.49 41.85 41.95 42.10 42.12 42.12 41.87 41.90 41.60 41.60 41.60 41.60
  LAYER   9       42.99 43.00 43.17 43.21 43.27 43.27 43.24 43.06 42.84 43.05 43.13 43.14 43.14
  LAYER  10       44.51 44.51 44.55 44.56 44.56 44.56 44.53 44.48 44.42 44.48 44.54 44.54 44.54
  LAYER  11       44.92 44.92 44.93 44.92 44.92 44.92 44.91 44.90 44.90 44.91 44.92 44.92 44.92
  LAYER  12       41.90 41.90 41.90 41.90 41.89 41.89 41.88 41.89 41.89 41.88 41.88 41.90 41.90
LOWER BOUNDARY    39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP=  300.00  HRS.            AIR TEMPERATURE= 27.13

                    1     2     3     4     5     6     7     8     9     10    11    12
UPPER BOUNDARY    27.82 27.82 27.82 27.82 27.82 27.82 27.13 27.13 27.13 27.13 27.13 27.13
  LAYER   1       28.76 28.76 28.75 28.67 28.06 28.12 28.81 29.27 29.84 30.01 29.99 29.99 29.99
  LAYER   2       31.77 31.76 31.66 31.38 28.91 29.15 30.13 31.57 33.36 33.66 33.61 33.61 33.61
  LAYER   3       33.76 33.76 33.52 34.14 33.33 33.56 34.20 34.64 34.83 34.68 34.60 34.60 34.60
  LAYER   4       33.78 33.84 35.22 36.83 37.80 38.05 38.30 37.71 36.46 35.64 35.53 35.53 35.53
  LAYER   5       35.06 35.06 37.58 38.19 38.92 39.11 39.23 38.70 38.09 37.55 37.42 37.42 37.42
  LAYER   6       37.86 37.90 39.13 39.46 39.90 40.12 40.19 39.80 39.39 39.06 38.96 38.96 38.96
  LAYER   7       39.01 39.10 40.04 40.26 40.68 40.77 40.81 40.53 40.41 40.00 39.92 39.91 39.91
  LAYER   8       40.65 40.93 41.28 41.40 41.64 41.68 41.71 41.51 41.40 41.21 41.17 41.17 41.17
  LAYER   9       42.13 42.16 42.53 42.61 42.73 42.74 42.73 42.53 42.30 42.46 42.46 42.48 42.48
  LAYER  10       43.80 43.82 43.93 43.95 43.96 43.96 43.96 43.88 43.84 43.87 43.91 43.92 43.92
  LAYER  11       44.81 44.81 44.82 44.83 44.83 44.82 44.82 44.81 44.80 44.80 44.82 44.82 44.82
  LAYER  12       41.89 41.89 41.88 41.89 41.89 41.88 41.88 41.88 41.89 41.88 41.88 41.89 41.88
LOWER BOUNDARY    39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP=  400.00  HRS.            AIR TEMPERATURE= 25.57

                    1     2     3     4     5     6     7     8     9     10    11    12
UPPER BOUNDARY    26.21 26.21 26.21 26.21 26.21 26.21 25.57 25.57 25.57 25.57 25.57 25.57
  LAYER   1       27.67 27.66 27.64 27.46 26.71 26.75 27.17 28.24 28.99 28.68 28.64 28.64 28.64
  LAYER   2       31.32 31.33 31.50 30.46 27.62 27.91 29.06 31.06 32.73 32.66 32.64 32.64 32.64
  LAYER   3       32.32 32.27 33.03 33.41 32.42 32.70 33.42 34.53 34.31 33.76 33.61 33.60 33.60
  LAYER   4       33.23 33.31 34.74 36.44 37.26 37.94 37.61 37.22 35.60 34.79 34.61 34.60 34.60
  LAYER   5       35.34 35.47 37.07 37.71 38.48 38.69 38.78 38.21 37.54 36.63 36.63 36.62 36.62
  LAYER   6       37.16 37.31 38.61 38.56 39.53 39.67 39.75 39.31 38.86 38.43 38.27 38.35 38.35
  LAYER   7       38.27 38.61 39.50 39.77 40.21 40.32 40.27 40.04 39.66 39.36 39.24 39.23 39.23
  LAYER   8       39.76 39.90 40.59 40.87 41.16 41.22 41.26 41.01 40.86 40.62 40.53 40.53 40.53
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     LAYER  9        41.36 41.48 41.88 42.06 42.23 42.30 42.28 42.03 41.76 41.69 41.67 41.67 41.67
     LAYER 10        43.14 43.18 43.30 43.43 43.48 43.48 43.47 43.38 43.33 43.34 43.30 43.30 43.30
     LAYER 11        44.24 44.25 44.28 44.28 44.30 44.30 44.28 44.28 44.27 44.27 44.28 44.28 44.28
     LAYER 12        41.88 41.88 41.88 41.88 41.88 41.88 41.88 41.88 41.88 41.88 41.88 41.88 41.88
  LOWER BOUNDARY     38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


         TIME AT THIS STEP=  500.00  HRS.           AIR TEMPERATURE= 24.06
     LAYER  1        26.53 26.53 26.30 25.66 25.33 25.40 25.86 27.40 27.67 27.63 27.63 27.63 27.63
     LAYER  2        30.42 30.46 30.44 27.67 28.22 26.64 27.88 31.62 32.10 31.89 31.96 31.96 31.96
     LAYER  3        31.63 31.66 33.03 31.77 31.30 31.76 32.59 34.13 33.67 33.00 33.01 33.00 33.00
     LAYER  4        33.76 33.62 33.84 35.00 36.63 36.03 37.23 36.08 35.26 34.00 33.83 33.82 33.82
     LAYER  5        34.76 34.89 36.46 37.10 37.66 38.19 38.26 37.86 36.93 36.07 35.81 35.80 35.80
     LAYER  6        36.63 36.68 38.03 38.43 39.00 39.18 39.34 38.77 38.30 37.73 37.50 37.48 37.48
     LAYER  7        37.80 37.77 38.84 39.23 39.89 39.81 39.87 39.81 39.33 38.72 38.50 38.40 38.40
     LAYER  8        39.08 39.28 40.13 40.34 40.58 40.73 40.78 40.48 40.33 40.01 39.89 39.88 39.88
     LAYER  9        40.89 40.83 41.41 41.64 41.74 41.77 41.77 41.63 41.38 41.33 41.28 41.26 41.26
     LAYER 10        42.52 42.60 42.87 42.93 43.02 43.02 43.01 42.81 42.85 42.84 42.83 42.83 42.83
     LAYER 11        43.63 43.68 43.82 43.84 43.88 43.88 43.88 43.83 43.83 43.81 43.82 43.82 43.82
     LAYER 12        41.87 41.87 41.87 41.87 41.87 41.87 41.87 41.87 41.87 41.87 41.87 41.87 41.87
  LOWER BOUNDARY     38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


         TIME AT THIS STEP=  600.00  HRS.           AIR TEMPERATURE= 22.50

                       1     2     3     4     5     6     7     8     9    10    11    12
  UPPER BOUNDARY     23.54 23.54 23.54 23.54 23.54 23.54 22.50 22.50 22.50 22.50 22.50 22.50
     LAYER  1        25.21 25.22 24.76 24.27 23.87 24.08 24.58 26.46 26.69 26.69 26.69 26.69 26.69
     LAYER  2        28.00 28.88 27.98 25.51 24.82 25.37 28.01 31.28 31.98 31.90 31.88 31.88 31.88
     LAYER  3        30.87 30.84 31.05 30.12 30.31 30.76 31.74 33.08 33.36 33.00 32.69 32.69 32.69
     LAYER  4        32.00 32.03 33.01 34.76 35.67 36.24 36.61 36.15 34.84 33.89 33.62 33.51 33.51
     LAYER  5        34.12 34.26 35.72 36.37 37.22 37.48 37.86 37.11 36.42 35.57 35.30 35.29 35.29
     LAYER  6        35.81 36.10 37.39 37.76 38.40 38.88 38.68 38.22 37.72 37.17 36.90 36.88 36.88
     LAYER  7        36.98 37.18 38.33 38.62 39.12 39.26 39.33 38.98 38.77 38.13 37.87 37.85 37.85
     LAYER  8        38.45 38.85 39.56 39.77 40.12 40.20 40.34 39.98 39.76 39.42 39.22 39.20 39.20
     LAYER  9        40.07 40.23 40.87 41.01 41.23 41.27 41.28 41.01 40.73 40.77 40.68 40.65 40.65
     LAYER 10        41.84 42.05 42.38 42.48 42.56 42.57 42.58 42.48 42.38 42.34 42.31 42.30 42.30
     LAYER 11        43.41 43.45 43.55 43.57 43.60 43.60 43.60 43.56 43.56 43.54 43.54 43.54 43.54
     LAYER 12        41.85 41.85 41.85 41.85 41.85 41.85 41.85 41.85 41.85 41.85 41.85 41.85 41.85
  LOWER BOUNDARY     38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


         TIME AT THIS STEP=  700.00  HRS.           AIR TEMPERATURE= 21.22

                       1     2     3     4     5     6     7     8     9    10    11    12
  UPPER BOUNDARY     22.30 22.30 22.30 22.30 22.30 22.30 21.22 21.22 21.22 21.22 21.22 21.22
     LAYER  1        23.76 23.76 23.33 22.93 22.72 22.66 23.36 25.47 25.87 25.86 25.87 25.87 25.87
     LAYER  2        26.04 26.04 25.93 24.01 23.87 24.19 26.88 30.67 31.83 31.77 31.73 31.72 31.72
     LAYER  3        29.15 29.16 28.82 26.84 29.20 29.63 30.89 33.14 33.12 32.68 32.46 32.46 32.46
     LAYER  4        31.70 31.81 31.92 33.76 35.07 35.62 35.87 35.87 34.69 33.43 33.24 33.23 33.23
     LAYER  5        33.64 33.76 34.83 35.80 36.49 36.82 37.07 36.61 36.00 35.20 34.93 34.90 34.90
     LAYER  6        35.34 35.51 36.84 37.04 37.74 37.98 38.11 37.71 37.28 36.72 36.43 36.41 36.41
     LAYER  7        36.39 36.69 37.86 37.95 38.80 38.67 38.77 38.46 38.27 37.65 37.37 37.34 37.34
     LAYER  8        37.85 38.08 38.98 39.17 39.55 39.65 39.71 39.45 39.29 38.91 38.67 38.65 38.65
     LAYER  9        39.47 39.66 40.32 40.47 40.71 40.76 40.76 40.52 40.23 40.25 40.11 40.09 40.09
     LAYER 10        41.38 41.62 41.89 41.97 42.06 42.11 42.11 41.98 41.91 41.87 41.80 41.79 41.79
     LAYER 11        42.98 43.04 43.17 43.20 43.24 43.24 43.24 43.22 43.20 43.17 43.15 43.15 43.15
     LAYER 12        41.83 41.83 41.83 41.83 41.83 41.83 41.83 41.83 41.83 41.83 41.83 41.83 41.83
  LOWER BOUNDARY     38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


                       1     2     3     4     5     6     7     8     9    10    11    12
  UPPER BOUNDARY     21.12 21.12 21.12 21.12 21.12 21.12 19.82 19.82 19.82 19.82 19.82 19.82
     LAYER  1        22.86 22.65 22.23 21.76 21.56 21.88 22.14 24.34 25.04 25.10 25.08 25.08 25.08
     LAYER  2        26.01 26.01 25.08 22.93 22.43 23.06 24.77 29.62 31.56 31.56 31.50 31.50 31.50
     LAYER  3        28.46 28.46 27.88 27.97 26.34 28.91 30.03 32.37 32.76 32.32 32.18 32.18 32.18
     LAYER  4        31.26 31.29 31.54 33.14 34.33 34.82 35.33 35.15 34.08 33.14 32.94 32.93 32.93
     LAYER  5        33.11 33.23 34.24 34.65 35.76 36.16 36.46 36.12 35.58 34.65 34.57 34.54 34.54
     LAYER  6        34.83 34.98 36.03 36.39 37.06 37.34 37.54 37.22 36.80 36.32 36.03 36.00 36.00
     LAYER  7        35.88 36.05 37.04 37.32 37.87 38.07 38.21 37.96 37.80 37.22 36.93 36.90 36.90
     LAYER  8        37.30 37.52 38.37 38.58 38.97 39.09 39.18 38.95 38.81 38.49 38.19 38.18 38.18
     LAYER  9        38.91 39.12 39.77 39.92 40.16 40.24 40.28 40.03 39.76 39.78 39.61 39.58 39.58
     LAYER 10        40.85 41.01 41.40 41.49 41.62 41.68 41.66 41.54 41.46 41.41 41.31 41.29 41.29
     LAYER 11        42.58 42.63 42.76 42.82 42.87 42.87 42.88 42.86 42.83 42.80 42.77 42.76 42.76
     LAYER 12        41.80 41.80 41.81 41.81 41.81 41.81 41.81 41.81 41.81 41.81 41.81 41.81 41.81
  LOWER BOUNDARY     38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


         TIME AT THIS STEP=  900.00  HRS.           AIR TEMPERATURE= 18.71

                       1     2     3     4     5     6     7     8     9    10    11    12
  UPPER BOUNDARY     20.04 20.04 20.04 20.04 20.04 20.04 18.71 18.71 18.71 18.71 18.71 18.71
     LAYER  1        21.02 21.03 21.26 20.72 20.47 20.58 20.91 22.74 24.12 24.33 24.31 24.31 24.31
     LAYER  2        25.10 25.12 24.33 21.92 21.38 21.84 23.81 27.42 30.84 31.26 31.18 31.18 31.18
     LAYER  3        27.02 27.88 27.32 27.12 27.45 28.00 29.06 30.96 32.12 32.00 31.87 31.87 31.87
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    LAYER  4      30.22 30.30 30.84 32.44 33.02 34.13 34.08 34.01 33.03 33.00 32.97 32.98 32.98
    LAYER  5      33.21 33.46 33.87 34.30 35.13 35.52 35.68 35.55 35.06 34.46 34.32 34.30 34.30
    LAYER  6      34.16 34.24 35.41 35.77 36.46 36.74 36.08 36.70 36.31 35.93 36.04 35.61 35.61
    LAYER  7      35.26 35.46 36.44 36.73 37.27 37.40 37.66 37.40 37.33 36.81 36.52 36.48 36.48
    LAYER  8      36.74 36.86 37.60 38.00 38.30 38.54 38.64 38.40 38.34 38.03 37.76 37.72 37.72
    LAYER  9      38.37 38.59 39.23 39.36 39.64 39.72 39.77 39.56 39.29 39.34 39.16 39.13 39.13
    LAYER 10      40.33 40.51 40.82 41.01 41.16 41.18 41.20 41.09 41.02 40.87 40.65 40.63 40.63
    LAYER 11      42.12 42.32 42.40 42.43 42.48 42.50 42.51 42.48 42.47 42.43 42.38 42.37 42.37
    LAYER 12      41.77 41.78 41.78 41.78 41.78 41.78 41.78 41.78 41.78 41.78 41.78 41.78 41.78
LOWER BOUNDARY    38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


         TIME AT THIS STEP= 1000.00  HRS.          AIR TEMPERATURE= 17.00

                    1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY    18.04 18.04 18.04 18.04 18.04 18.04 17.00 17.00 17.00 17.00 17.00 17.00
    LAYER  1      20.44 20.46 20.16 19.72 19.47 19.58 19.71 21.30 22.98 23.50 23.50 23.58 23.58
    LAYER  2      23.40 23.58 23.15 20.82 20.36 20.88 22.23 25.46 28.56 30.65 30.61 30.60 30.60
    LAYER  3      25.80 25.74 26.23 26.37 26.59 27.10 26.06 29.84 31.65 31.85 31.77 31.76 31.76
    LAYER  4      27.64 27.83 29.30 31.08 32.03 33.42 33.95 33.83 33.00 32.59 32.46 32.44 32.44
    LAYER  5      31.95 31.96 32.69 33.61 34.48 34.88 35.20 34.87 34.54 34.16 33.06 33.03 33.03
    LAYER  6      33.58 33.70 34.60 35.11 35.62 36.12 36.38 36.14 35.81 35.66 35.31 35.27 35.27
    LAYER  7      34.64 34.80 35.78 36.06 36.66 36.90 37.00 36.92 36.63 36.41 36.16 36.13 36.13
    LAYER  8      36.12 36.34 37.20 37.41 37.83 37.98 38.11 37.98 37.86 37.56 37.36 37.33 37.33
    LAYER  9      37.80 38.02 38.59 38.84 39.12 39.21 39.27 39.06 38.83 38.59 38.72 38.69 38.69
    LAYER 10      39.83 40.03 40.44 40.53 40.65 40.72 40.78 40.69 40.58 40.56 40.42 40.39 40.39
    LAYER 11      41.69 41.83 42.01 42.06 42.11 42.13 42.14 42.12 42.10 42.06 42.00 41.99 41.99
    LAYER 12      41.74 41.75 41.75 41.75 41.75 41.75 41.75 41.75 41.75 41.75 41.75 41.75 41.75
LOWER BOUNDARY    38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00
         TIME AT THIS STEP= 1100.00  HRS.          AIR TEMPERATURE= 16.00

                    1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY    16.14 16.14 16.14 16.14 16.14 16.14 16.00 16.00 16.00 16.00 16.00 16.00
    LAYER  1      16.39 16.39 16.19 16.76 16.66 16.64 16.70 20.12 21.71 22.66 22.64 22.63 22.63
    LAYER  2      22.13 22.16 21.83 19.85 19.48 19.81 21.19 24.17 27.03 30.43 30.35 30.34 30.34
    LAYER  3      24.14 24.16 24.76 25.61 25.84 26.30 27.20 28.59 30.15 31.61 31.39 31.38 31.38
    LAYER  4      26.13 26.16 27.81 31.63 32.32 32.77 33.27 33.08 32.00 32.23 32.09 32.07 32.07
    LAYER  5      31.76 31.81 31.99 32.66 33.66 34.23 34.88 34.31 33.63 33.79 33.62 33.59 33.59
    LAYER  6      33.27 33.37 34.06 34.52 35.23 35.53 35.76 35.57 35.23 35.17 34.97 34.93 34.93
    LAYER  7      34.28 34.40 35.16 35.49 36.07 36.31 36.51 36.37 36.32 36.03 35.81 35.77 35.77
    LAYER  8      35.66 35.89 36.63 36.84 37.28 37.43 37.58 37.45 37.37 37.19 36.96 36.94 36.94
    LAYER  9      37.29 37.51 38.15 38.30 38.59 38.68 38.77 38.60 38.36 38.49 38.33 38.30 38.30
    LAYER 10      39.32 39.53 39.96 40.05 40.21 40.26 40.29 40.21 40.15 40.13 40.01 39.98 39.98
    LAYER 11      41.27 41.41 41.62 41.68 41.74 41.76 41.77 41.76 41.74 41.70 41.63 41.61 41.61
    LAYER 12      41.70 41.71 41.72 41.72 41.72 41.72 41.72 41.72 41.72 41.72 41.72 41.72 41.72
LOWER BOUNDARY    38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


         TIME AT THIS STEP= 1200.00  HRS.          AIR TEMPERATURE= 15.72

                    1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY    17.35 17.35 17.35 17.35 17.35 17.35 15.72 15.72 15.72 15.72 15.72 15.72
    LAYER  1      18.86 18.66 18.42 18.01 17.77 17.64 17.78 19.13 20.87 22.10 22.10 22.09 22.09
    LAYER  2      21.58 21.56 21.28 19.21 18.96 19.06 20.28 23.07 26.89 28.75 28.73 28.71 28.71
    LAYER  3      23.68 23.69 24.27 25.33 25.27 25.61 26.40 27.74 28.99 30.84 30.66 30.67 30.67
    LAYER  4      25.78 25.81 27.27 31.59 31.90 32.22 32.62 32.49 31.80 31.98 31.86 31.96 31.96
    LAYER  5      31.56 31.59 31.94 32.69 33.37 33.67 33.84 33.74 33.30 33.41 33.34 33.32 33.32
    LAYER  6      32.94 33.04 33.74 34.12 34.69 34.96 35.17 35.01 34.74 34.76 34.63 34.60 34.60
    LAYER  7      33.90 34.04 34.78 35.04 35.63 35.75 35.94 35.83 35.82 35.60 35.46 35.42 35.42
    LAYER  8      35.26 35.46 36.16 36.34 36.72 36.88 37.02 36.93 36.86 36.76 36.61 36.57 36.57
    LAYER  9      36.84 37.06 37.66 37.80 38.07 38.16 38.26 38.11 37.88 38.07 37.86 37.81 37.81
    LAYER 10      38.85 39.06 39.48 39.58 39.74 39.80 39.84 39.77 39.72 39.72 39.62 39.58 39.58
    LAYER 11      40.85 41.01 41.23 41.28 41.36 41.38 41.40 41.39 41.37 41.34 41.27 41.26 41.26
    LAYER 12      41.86 41.87 41.88 41.88 41.88 41.89 41.89 41.89 41.89 41.88 41.88 41.88 41.88
LOWER BOUNDARY    38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


         TIME AT THIS STEP= 1300.00  HRS.          AIR TEMPERATURE= 14.88

                    1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY    16.67 16.67 16.67 16.67 16.67 16.67 14.88 14.88 14.88 14.88 14.88 14.88
    LAYER  1      18.02 18.03 17.79 17.34 17.08 17.15 17.06 18.43 20.02 21.33 21.37 21.37 21.37
    LAYER  2      21.06 21.07 20.78 18.59 18.01 18.41 19.88 22.44 25.18 28.03 29.01 29.00 29.00
    LAYER  3      23.28 23.30 22.80 24.68 24.83 25.15 25.79 27.20 28.62 30.34 30.37 30.38 30.38
    LAYER  4      25.50 25.52 27.03 31.28 31.98 31.99 32.11 32.03 31.42 31.66 31.63 31.63 31.63
    LAYER  5      31.25 31.29 31.64 32.44 33.12 33.30 33.44 33.27 32.96 33.16 33.14 33.13 33.13
    LAYER  6      32.58 32.66 33.40 33.80 34.34 34.52 34.66 34.53 34.30 34.44 34.38 34.36 34.36
    LAYER  7      33.53 33.67 34.43 34.68 35.13 35.29 35.43 35.26 35.30 35.25 35.16 35.13 35.13
    LAYER  8      34.87 35.06 35.74 35.92 36.26 36.40 36.52 36.46 36.44 36.37 36.28 36.24 36.24
    LAYER  9      36.43 36.64 37.21 37.38 37.60 37.70 37.78 37.66 37.44 37.66 37.59 37.56 37.56
    LAYER 10      38.41 38.62 39.04 39.13 39.29 39.36 39.39 39.34 39.29 39.32 39.24 39.20 39.20
    LAYER 11      40.45 40.62 40.85 40.90 40.98 41.01 41.03 41.02 41.01 40.98 40.92 40.90 40.90
    LAYER 12      41.62 41.63 41.64 41.64 41.64 41.66 41.66 41.66 41.66 41.65 41.64 41.64 41.64

         TIME AT THIS STEP= 1400.00  HRS.          AIR TEMPERATURE= 14.33
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                      1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY     15.10 15.10 15.10 15.10 15.10 15.10 14.33 14.33 14.33 14.33 14.33 14.33
  LAYER   1        17.50 17.50 17.25 16.75 16.53 16.55 16.46 17.65 19.45 20.67 20.75 20.75 20.75
  LAYER   2        20.61 20.63 20.31 18.05 17.47 17.55 18.55 21.93 25.59 28.23 28.36 28.37 28.37
  LAYER   3        22.90 22.93 23.54 24.44 24.83 24.85 25.44 26.90 28.30 29.79 29.95 29.88 29.88
  LAYER   4        26.16 26.22 28.78 30.89 31.69 31.85 31.88 31.87 30.89 31.60 31.60 31.58 31.58
  LAYER   5        29.83 30.90 31.70 32.17 32.82 33.05 33.13 32.98 32.51 32.65 32.89 32.88 32.88
  LAYER   6        32.14 32.27 33.17 33.59 34.05 34.16 34.26 34.14 33.89 34.13 34.12 34.09 34.09
  LAYER   7        33.11 33.26 34.10 34.34 34.78 34.92 35.02 34.94 34.87 34.91 34.88 34.88 34.88
  LAYER   8        34.46 34.65 35.27 35.65 35.88 35.99 36.06 36.03 36.03 36.02 35.98 35.94 35.94
  LAYER   9        35.92 36.23 36.61 36.94 37.18 37.27 37.33 37.22 37.03 37.26 37.25 37.22 37.22
  LAYER  10        37.99 38.21 38.63 38.71 38.86 38.92 38.96 38.92 38.66 38.93 38.88 38.85 38.85
  LAYER  11        40.06 40.24 40.47 40.53 40.60 40.64 40.67 40.65 40.55 40.55 40.59 40.58 40.58
  LAYER  12        41.57 41.58 41.60 41.60 41.60 41.60 41.60 41.61 41.60 41.60 41.60 41.60 41.60
LOWER BOUNDARY     39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00
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        TIME AT THIS STEP= 1500.00  HRS.          AIR TEMPERATURE= 13.84

                      1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY     15.58 15.58 15.58 15.58 15.58 15.58 13.84 13.84 13.84 13.84 13.84 13.84
  LAYER   1        17.06 17.07 16.61 16.34 16.08 16.14 16.99 17.27 18.56 20.19 20.27 20.27 20.27
  LAYER   2        20.19 20.22 19.82 17.53 17.04 17.42 18.56 21.48 25.22 27.74 27.83 27.82 27.82
  LAYER   3        22.50 22.54 23.21 24.00 24.38 24.61 25.21 26.84 27.72 28.36 28.50 28.49 28.49
  LAYER   4        24.78 24.85 28.51 30.41 31.61 31.80 31.88 31.80 30.28 31.20 31.24 31.23 31.23
  LAYER   5        30.23 30.33 31.51 31.98 32.74 32.88 32.97 32.88 32.04 32.50 32.56 32.55 32.55
  LAYER   6        31.57 31.90 32.89 33.23 33.79 33.93 34.03 33.82 33.50 33.77 33.80 33.78 33.78
  LAYER   7        32.83 32.91 33.74 34.03 34.48 34.82 34.71 34.59 34.60 34.56 34.56 34.55 34.55
  LAYER   8        34.08 34.28 35.01 35.19 35.63 35.64 35.72 35.66 35.65 35.66 35.65 35.64 35.64
  LAYER   9        35.61 35.82 36.42 36.56 36.80 36.88 36.94 36.83 36.64 36.81 36.83 36.80 36.80
  LAYER  10        37.58 37.80 38.21 38.30 38.48 38.51 38.56 38.52 38.48 38.58 38.54 38.51 38.51
  LAYER  11        39.88 39.87 40.10 40.16 40.24 40.28 40.31 40.31 40.31 40.31 40.26 40.23 40.23
  LAYER  12        41.52 41.54 41.55 41.55 41.55 41.55 41.56 41.55 41.55 41.55 41.55 41.55 41.55
LOWER BOUNDARY     39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00
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        TIME AT THIS STEP= 1600.00  HRS.          AIR TEMPERATURE= 13.48

                      1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY     15.34 15.34 15.34 15.34 15.34 15.34 13.48 13.48 13.48 13.48 13.48 13.48
  LAYER   1        16.71 16.72 16.48 16.01 15.78 15.82 15.64 17.00 18.57 18.78 19.00 19.09 19.09
  LAYER   2        19.77 19.51 18.80 17.29 16.72 17.10 18.22 21.10 24.78 27.30 27.52 27.51 27.51
  LAYER   3        22.02 22.08 22.90 23.58 24.17 24.42 25.03 26.40 27.25 28.92 29.09 29.08 29.08
  LAYER   4        24.24 24.35 28.22 29.90 31.71 31.82 31.82 31.79 29.71 30.61 30.74 30.72 30.72
  LAYER   5        29.39 29.51 31.27 31.86 32.60 32.74 32.62 32.51 31.88 32.03 32.13 32.11 32.11
  LAYER   6        31.67 31.90 32.66 33.05 33.56 33.71 33.80 33.57 33.25 33.35 33.42 33.40 33.40
  LAYER   7        32.67 32.75 33.53 33.80 34.26 34.37 34.46 34.30 34.29 34.18 34.22 34.20 34.20
  LAYER   8        33.65 34.00 34.71 34.90 35.23 35.33 35.41 35.33 35.31 35.28 35.32 35.30 35.30
  LAYER   9        35.29 35.49 36.07 36.21 36.45 36.53 36.59 36.47 36.29 36.56 36.60 36.57 36.57
  LAYER  10        37.20 37.42 37.83 37.93 38.06 38.14 38.16 38.15 38.12 38.20 38.21 38.18 38.18
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        TIME AT THIS STEP= 1700.00  HRS.          AIR TEMPERATURE= 13.27

                      1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY     15.14 15.14 15.14 15.14 15.14 15.14 13.27 13.27 13.27 13.27 13.27 13.27
  LAYER   1        16.42 16.45 16.27 15.81 15.56 15.61 15.41 16.78 18.28 19.39 19.54 19.53 19.53
  LAYER   2        19.29 19.37 19.34 17.06 16.51 16.69 17.69 20.61 24.43 26.66 26.88 26.97 26.97
  LAYER   3        21.39 21.52 22.61 23.26 24.02 24.28 24.89 26.19 26.90 28.23 28.50 28.49 28.49
  LAYER   4        23.46 23.65 25.92 29.47 31.59 31.74 31.87 31.65 29.37 29.78 30.02 30.00 30.00
  LAYER   5        28.11 28.37 30.95 31.66 32.46 32.60 32.69 32.39 31.82 31.97 31.86 31.86 31.86
  LAYER   6        31.65 31.72 32.40 32.87 33.39 33.52 33.61 33.39 33.04 33.13 33.14 33.14 33.14
  LAYER   7        32.43 32.64 33.29 33.68 34.02 34.14 34.22 34.06 34.03 33.88 33.90 33.89 33.89
  LAYER   8        33.60 33.76 34.45 34.83 34.96 35.06 35.13 35.04 35.02 34.95 34.98 34.96 34.96
  LAYER   9        35.01 35.20 35.77 35.91 36.14 36.22 36.27 36.15 35.97 36.20 36.25 36.23 36.23
  LAYER  10        36.86 37.08 37.48 37.58 37.73 37.79 37.83 37.80 37.78 37.85 37.88 37.85 37.85
  LAYER  11        38.97 39.17 39.41 39.46 39.55 39.59 39.63 39.64 39.65 39.68 39.65 39.62 39.62
  LAYER  12        41.42 41.44 41.45 41.45 41.46 41.46 41.46 41.46 41.46 41.46 41.46 41.46 41.46
LOWER BOUNDARY     39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00
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        TIME AT THIS STEP= 1800.00  HRS.          AIR TEMPERATURE= 13.20

                      1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY     15.06 15.06 15.06 15.06 15.06 15.06 13.20 13.20 13.20 13.20 13.20 13.20
  LAYER   1        16.25 16.26 16.15 15.72 15.46 15.53 15.31 16.61 18.09 19.00 19.17 19.17 19.17
  LAYER   2        18.87 18.97 19.18 16.94 16.42 16.79 17.86 20.60 24.10 25.90 26.27 26.28 26.28
  LAYER   3        20.81 20.98 22.38 23.05 23.91 24.19 24.80 26.00 26.58 27.38 27.72 27.71 27.71
  LAYER   4        22.72 22.93 25.88 29.18 31.45 31.64 31.81 31.48 28.06 28.81 29.14 29.13 29.13
  LAYER   5        27.02 27.28 30.55 31.77 32.29 32.45 32.56 32.17 31.84 31.81 31.83 31.83 31.83
  LAYER   6        31.23 31.38 32.06 32.66 33.20 33.34 33.43 33.16 32.83 32.97 33.00 33.00 33.00
  LAYER   7        32.04 32.19 33.01 33.35 33.60 33.93 34.01 33.84 33.81 33.68 33.71 33.70 33.70
  LAYER   8        33.28 33.45 34.17 34.37 34.71 34.81 34.88 34.78 34.78 34.70 34.72 34.71 34.71
  LAYER   9        34.70 34.90 35.48 35.62 35.85 35.93 35.99 35.87 35.69 35.90 35.95 35.94 35.94
  LAYER  10        36.53 36.75 37.16 37.25 37.40 37.46 37.51 37.48 37.45 37.52 37.56 37.54 37.54
  LAYER  11        38.84 38.84 39.08 39.14 39.23 39.27 39.31 39.32 39.33 39.35 39.35 39.32 39.32
  LAYER  12        41.38 41.38 41.40 41.40 41.40 41.41 41.41 41.41 41.41 41.41 41.41 41.41 41.41
LOWER BOUNDARY     39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00
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              TIME AT THIS STEP= 1900.00  HRS.           AIR TEMPERATURE= 13.27

                    1      2      3      4      5      6      7      8      9     10     11     12
UPPER BOUNDARY    15.14  15.14  15.14  15.14  15.14  15.14  13.27  13.27  13.27  13.27  13.27  13.27
   LAYER   1      16.24  16.27  16.19  15.78  15.83  15.58  15.24  15.59  16.01  16.78  16.88  16.90  16.90
   LAYER   2      16.72  16.81  19.10  19.95  18.44  16.80  17.84  20.47  23.84  25.29  25.58  25.58  25.58
   LAYER   3      20.55  20.70  22.25  22.98  23.88  24.15  24.78  25.84  26.30  26.71  26.97  26.97  26.97
   LAYER   4      22.38  22.57  25.45  28.99  31.28  31.54  31.74  31.27  28.78  28.12  28.35  28.38  28.38
   LAYER   5      28.49  28.74  30.10  31.82  32.12  32.30  32.43  32.00  31.40  31.80  31.84  31.83  31.83
   LAYER   6      30.58  30.78  31.97  32.47  33.00  33.15  33.28  32.95  32.60  32.80  32.88  32.88  32.88
   LAYER   7      31.96  31.98  32.81  33.13  33.58  33.72  33.81  33.83  32.58  33.49  33.53  33.53  33.53
   LAYER   8      33.04  33.15  33.81  34.12  34.47  34.57  34.66  34.64  34.53  34.47  34.51  34.50  34.50
   LAYER  12      41.30  41.32  41.34  41.34  41.35  41.35  41.35  41.36  41.36  41.36  41.36  41.35  41.36
LOWER BOUNDARY    39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00


              TIME AT THIS STEP= 2000.00  HRS.           AIR TEMPERATURE= 13.48

                    1      2      3      4      5      6      7      8      9     10     11     12
UPPER BOUNDARY    15.34  15.34  15.34  15.34  15.34  15.34  13.48  13.48  13.48  13.48  13.48  13.48
   LAYER   1      16.38  16.40  16.34  16.02  15.70  15.75  15.40  15.70  16.00  16.76  16.88  16.88  16.88
   LAYER   2      16.70  16.81  19.15  17.08  18.89  18.93  17.93  20.47  23.75  25.10  25.25  25.28  25.28
   LAYER   3      20.43  20.80  22.21  22.98  23.88  24.16  24.77  25.74  26.16  26.48  26.81  26.82  26.83
   LAYER   4      22.16  22.38  25.33  28.88  31.12  31.42  31.88  31.08  28.59  27.88  27.88  27.88  27.88
   LAYER   5      28.04  28.33  29.71  31.43  32.00  32.17  32.31  31.98  31.14  31.68  31.70  31.70  31.70
   LAYER   6      29.88  30.13  31.87  32.29  32.62  32.98  33.08  32.61  32.38  32.61  32.66  32.67  32.67
   LAYER   7      31.62  31.88  32.85  32.94  33.39  33.52  33.62  33.43  33.30  33.29  33.34  33.34  33.34
   LAYER   8      32.88  32.98  33.71  33.90  34.24  34.38  34.42  34.32  34.29  34.25  34.30  34.30  34.29
   LAYER   9      34.15  34.34  34.84  35.08  35.32  35.40  35.48  35.34  35.17  35.39  35.46  35.48  35.48
   LAYER  10      35.92  36.14  36.56  36.65  36.81  36.87  36.92  36.89  36.88  36.93  36.98  36.98  36.98
   LAYER  11      38.02  38.23  38.48  38.53  38.63  38.67  38.71  38.73  38.74  38.75  38.76  38.77  38.77
   LAYER  12      41.24  41.26  41.28  41.29  41.28  41.30  41.30  41.30  41.30  41.30  41.30  41.30  41.30
LOWER BOUNDARY    39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00


              TIME AT THIS STEP= 2100.00  HRS.           AIR TEMPERATURE= 13.84

                    1      2      3      4      5      6      7      8      9     10     11     12
UPPER BOUNDARY    15.88  15.88  15.88  15.88  15.88  15.88  13.84  13.84  13.84  13.84  13.84  13.84
   LAYER   1      16.80  16.84  16.61  16.21  16.00  16.05  15.78  16.95  16.29  16.88  18.03  18.04  18.04
   LAYER   2      16.77  18.90  19.31  17.32  18.65  17.18  18.14  20.58  23.78  25.11  25.23  25.23  25.23
   LAYER   3      20.39  20.57  22.28  23.02  23.90  24.22  24.83  25.89  26.11  26.46  26.66  26.66  26.66
   LAYER   4      22.00  22.25  25.25  28.75  30.98  31.28  31.57  30.83  28.47  27.84  27.89  27.90  27.90
   LAYER   5      25.84  25.98  29.44  31.20  31.88  32.08  32.30  31.94  30.90  31.48  31.58  31.58  31.59
   LAYER   6      28.24  29.61  31.72  32.08  32.72  32.88  32.94  32.67  32.18  32.41  32.48  32.48  32.48
   LAYER   7      31.57  31.89  32.46  32.74  33.24  33.37  33.46  33.28  33.15  33.08  33.14  33.14  33.14
   LAYER   8      32.62  32.78  33.50  33.80  34.04  34.15  34.23  34.11  34.07  34.03  34.08  34.08  34.08
   LAYER   9      33.93  34.11  34.70  34.84  35.08  35.17  35.23  35.11  34.94  35.14  35.22  35.22  35.22
   LAYER  10      35.88  35.87  36.29  36.38  36.54  36.60  36.65  36.62  36.60  36.67  36.73  36.72  36.72
   LAYER  11      37.74  37.85  38.20  38.28  38.35  38.40  38.44  38.45  38.47  38.48  38.53  38.61  38.61
   LAYER  12      41.18  41.20  41.22  41.23  41.23  41.24  41.24  41.24  41.24  41.25  41.25  41.24  41.24
LOWER BOUNDARY    39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00


              TIME AT THIS STEP= 2200.00  HRS.           AIR TEMPERATURE= 14.33

                    1      2      3      4      5      6      7      8      9     10     11     12
UPPER BOUNDARY    16.10  16.10  16.10  16.10  16.10  16.10  14.33  14.33  14.33  14.33  14.33  14.33
   LAYER   1      16.97  17.01  17.00  16.82  16.42  16.45  16.19  17.31  18.60  19.28  19.34  19.34  19.34
   LAYER   2      18.80  19.11  15.97  17.87  17.23  17.84  18.45  20.81  23.86  25.20  25.33  25.33  25.33
   LAYER   3      20.49  20.88  22.38  23.15  24.02  24.35  24.94  25.71  26.13  26.51  26.60  26.61  26.61
   LAYER   4      22.01  22.28  25.28  28.85  30.80  31.16  31.47  30.63  28.39  27.64  27.80  27.81  27.81
   LAYER   5      25.43  25.74  29.23  30.94  31.98  32.00  32.00  31.67  30.68  31.28  31.37  31.37  31.37
   LAYER   6      28.85  29.11  31.82  31.99  32.63  32.73  32.81  32.53  32.00  32.20  32.30  32.28  32.28
   LAYER  10      35.38  35.81  36.03  36.12  36.28  36.35  36.40  36.37  36.35  36.41  36.46  36.48  36.48
   LAYER  11      37.47  37.88  37.93  37.99  38.09  38.13  38.16  38.20  38.21  38.24  38.27  38.27  38.27
   LAYER  12      41.12  41.14  41.16  41.17  41.17  41.18  41.18  41.18  41.19  41.19  41.19  41.19  41.19
LOWER BOUNDARY    39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00  39.00


              TIME AT THIS STEP= 2300.00  HRS.           AIR TEMPERATURE= 14.98

                    1      2      3      4      5      6      7      8      9     10     11     12
UPPER BOUNDARY    16.67  16.67  16.67  16.67  16.67  16.67  14.98  14.98  14.98  14.98  14.98  14.98
   LAYER   1      17.47  17.51  17.50  17.15  16.96  17.00  16.72  17.79  19.02  19.66  19.74  19.74  19.74
   LAYER   2      19.33  19.46  19.93  18.14  17.72  18.01  18.89  21.11  24.06  25.33  25.46  25.46  25.46
   LAYER   3      20.74  20.82  22.59  23.33  24.20  24.52  25.10  25.78  26.20  26.59  26.68  26.69  26.69
   LAYER   4      22.16  22.39  25.32  28.85  30.67  31.04  31.37  30.47  28.39  27.88  27.94  27.94  27.94
   LAYER   5      25.35  25.57  29.07  30.57  31.92  31.88  32.00  31.80  30.85  31.07  31.18  31.18  31.18
   LAYER   6      28.58  28.85  31.30  31.94  32.54  32.64  32.68  32.43  31.97  32.00  32.07  32.07  32.07
   LAYER   7      30.70  30.89  32.03  32.47  32.98  33.10  33.15  32.88  32.85  32.65  32.72  32.72  32.72
   LAYER   8      32.00  32.15  33.07  33.32  33.71  33.61  33.87  33.78  32.70  33.54  33.65  33.65  33.65
   LAYER   9      33.32  33.56  34.24  34.40  34.67  34.75  34.81  34.89  34.62  34.68  34.76  34.77  34.77
   LAYER 10       35.10 35.34 35.75 35.88 36.06 36.11 36.16 36.12 36.11 36.17 36.24 36.24 36.24
   LAYER 11       37.21 37.43 37.86 37.74 37.84 37.88 37.83 37.98 37.96 37.99 38.03 38.03 38.03
   LAYER 12       41.08 41.08 41.10 41.10 41.11 41.12 41.12 41.12 41.12 41.13 41.13 41.13 41.13
 LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


      TIME AT THIS STEP= 2400.00  HRS.          AIR TEMPERATURE= 15.72

                    1     2     3     4     5     6     7     8     9    10    11    12
 UPPER BOUNDARY   17.38 17.38 17.38 17.38 17.38 17.38 15.72 15.72 15.72 15.72 15.72 15.72
   LAYER  1       18.07 18.11 18.12 17.79 17.81 17.65 17.38 18.37 19.84 20.16 20.23 20.23 20.23
   LAYER  2       19.77 19.81 20.37 18.71 18.32 18.58 19.38 21.81 24.26 25.40 25.62 25.63 25.63
   LAYER  3       21.06 21.28 22.67 23.56 24.46 24.77 25.31 25.91 26.32 26.67 26.79 26.79 26.79
   LAYER  4       22.35 22.62 25.42 28.46 30.57 30.84 31.37 30.34 28.37 27.80 27.87 27.87 27.87
   LAYER  5       26.29 25.88 26.63 30.42 31.88 31.97 31.90 31.70 30.47 30.65 30.87 30.87 30.87
   LAYER  6       28.23 28.50 31.08 31.88 32.48 32.58 32.81 32.33 31.81 31.88 31.89 31.89 31.89
   LAYER  7       30.12 30.80 31.86 32.38 32.88 32.98 33.06 32.85 32.74 32.57 32.58 32.58 32.58
   LAYER  8       31.67 31.99 32.92 33.16 33.56 33.56 33.72 33.60 33.55 33.43 33.46 33.46 33.46
   LAYER  9       33.16 33.29 34.02 34.20 34.40 34.57 34.62 34.50 34.34 34.48 34.55 34.55 34.55
   LAYER 10       34.84 35.06 35.54 35.85 35.82 35.80 35.84 36.01 35.69 35.94 36.01 36.01 36.01
   LAYER 11       36.96 37.18 37.44 37.60 37.60 37.65 37.69 37.72 37.73 37.76 37.80 37.81 37.81
   LAYER 12       40.96 41.01 41.04 41.04 41.05 41.06 41.06 41.06 41.06 41.07 41.07 41.07 41.07
 LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


      TIME AT THIS STEP= 2500.00  HRS.          AIR TEMPERATURE= 16.80

                    1     2     3     4     5     6     7     8     9    10    11    12
 UPPER BOUNDARY   18.14 18.14 18.14 18.14 18.14 18.14 16.80 16.80 16.80 16.80 16.80 16.80
   LAYER  1       18.76 18.82 18.84 18.54 18.28 18.41 18.12 19.08 20.15 20.72 20.79 20.79 20.79
   LAYER  2       20.28 20.46 20.91 19.36 19.02 19.27 19.89 21.98 24.57 25.88 25.81 25.82 25.82
   LAYER  3       21.43 21.86 23.21 22.88 24.78 25.07 25.56 26.10 26.48 26.76 26.90 26.90 26.90
   LAYER  4       22.89 22.80 25.56 28.42 30.40 30.88 31.18 30.35 28.41 27.91 28.01 28.01 28.01
   LAYER  8       31.82 31.86 32.81 33.04 33.43 33.53 33.60 33.47 33.42 33.31 33.34 33.34 33.34
   LAYER  9       33.04 33.17 33.67 34.04 34.32 34.40 34.48 34.36 34.18 34.32 34.27 34.36 34.36
   LAYER 10       34.63 34.84 35.33 35.44 35.62 35.68 35.72 35.71 35.66 35.73 35.79 35.80 35.80
   LAYER 11       36.72 36.94 37.21 37.27 37.36 37.43 37.47 37.50 37.51 37.54 37.58 37.59 37.59
   LAYER 12       40.82 40.85 40.87 40.88 40.98 40.99 40.98 41.00 41.00 41.00 41.01 41.01 41.01
 LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


      TIME AT THIS STEP= 2600.00  HRS.          AIR TEMPERATURE= 17.80

                    1     2     3     4     5     6     7     8     9    10    11    12
 UPPER BOUNDARY   19.04 19.04 19.04 19.04 19.04 19.04 17.80 17.80 17.80 17.80 17.80 17.80
   LAYER  1       19.58 19.63 19.66 19.38 19.24 19.27 18.86 19.88 20.86 21.37 21.43 21.43 21.43
   LAYER  2       20.89 21.06 21.53 20.14 19.63 20.08 20.89 22.52 24.92 25.90 26.03 26.03 26.03
   LAYER  3       21.90 22.13 23.62 24.28 25.13 25.42 25.89 26.38 26.68 26.91 27.03 27.03 27.03
   LAYER  4       22.93 23.23 25.79 28.41 30.44 30.80 31.11 30.20 28.66 27.98 28.08 28.08 28.08
   LAYER  5       25.26 25.69 28.75 30.02 31.76 31.91 31.88 31.51 30.38 30.43 30.57 30.57 30.57
   LAYER  6       27.64 28.08 30.74 31.61 32.28 32.42 32.49 32.13 31.77 31.87 31.90 31.90 31.90
   LAYER  7       29.21 29.83 31.62 32.12 32.87 32.90 32.87 32.63 32.54 32.41 32.43 32.44 32.44
   LAYER  8       31.85 31.91 32.69 32.91 33.30 33.41 33.48 33.35 33.30 33.20 33.23 33.23 33.23
   LAYER  9       32.91 33.06 33.72 33.88 34.16 34.25 34.31 34.19 34.04 34.17 34.22 34.23 34.23
   LAYER 10       34.45 34.65 35.13 35.24 35.42 35.49 35.55 35.52 35.50 35.54 35.60 35.61 35.61
   LAYER 11       36.50 36.71 36.99 37.06 37.16 37.22 37.29 37.29 37.30 37.33 37.38 37.38 37.38
   LAYER 12       40.85 40.88 40.91 40.91 40.92 40.93 40.93 40.94 40.94 40.94 40.95 40.95 40.95
 LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


      TIME AT THIS STEP= 2700.00  HRS.          AIR TEMPERATURE= 18.71

                    1     2     3     4     5     6     7     8     9    10    11    12
 UPPER BOUNDARY   20.04 20.04 20.04 20.04 20.04 20.04 18.71 18.71 18.71 18.71 18.71 18.71
   LAYER  1       20.49 20.54 20.57 20.33 20.21 20.33 19.94 20.73 21.84 22.09 22.14 22.15 22.15
   LAYER  2       21.62 21.76 22.24 21.00 20.73 20.82 21.48 23.14 25.31 26.15 26.28 26.28 26.28
   LAYER  3       22.49 22.70 24.11 24.71 25.57 25.84 26.26 26.64 26.92 27.07 27.18 27.19 27.19
   LAYER  4       23.38 23.68 26.06 28.44 30.41 30.76 31.06 30.17 28.88 28.01 28.11 28.12 28.12
   LAYER  5       25.48 25.84 28.73 29.90 31.70 31.87 31.94 31.41 30.35 30.28 30.39 30.39 30.39
   LAYER  6       27.59 27.98 30.61 31.48 32.18 32.34 32.42 32.03 31.69 31.79 31.83 31.83 31.83
   LAYER  7       29.06 29.40 31.70 32.00 32.87 32.70 32.79 32.53 32.43 32.31 32.35 32.35 32.35
   LAYER  8       31.76 31.84 32.66 32.77 33.18 33.29 33.37 33.23 33.18 33.08 33.12 33.12 33.12
   LAYER  9       32.78 32.94 33.58 33.72 34.02 34.11 34.17 34.05 33.90 34.03 34.08 34.09 34.09
   LAYER 10       34.28 34.49 34.96 35.06 35.24 35.31 35.37 35.35 35.32 35.37 35.42 35.44 35.44
   LAYER 11       36.29 36.51 36.79 36.88 36.98 37.02 37.07 37.09 37.11 37.13 37.18 37.19 37.19
   LAYER 12       40.78 40.82 40.84 40.84 40.85 40.86 40.87 40.87 40.87 40.88 40.88 40.88 40.88
 LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


      TIME AT THIS STEP= 2800.00  HRS.          AIR TEMPERATURE= 19.82

                    1     2     3     4     5     6     7     8     9    10    11    12
 UPPER BOUNDARY   21.12 21.12 21.12 21.12 21.12 21.12 19.82 19.82 19.82 19.82 19.82 19.82
   LAYER  1       21.50 21.54 21.56 21.37 21.26 21.26 21.00 21.69 22.90 22.86 22.93 22.93 22.93
   LAYER  2       22.46 22.57 23.02 21.86 21.71 21.67 22.38 23.82 25.75 26.45 26.56 26.56 26.56
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      LAYER  6      27.71 28.02 30.51 31.21 32.09 32.27 32.30 31.99 31.81 31.88 31.78 31.78 31.78
      LAYER  7      29.08 29.34 31.57 31.96 32.47 32.63 32.71 32.45 32.34 32.30 32.28 32.28 32.28
      LAYER  8      31.66 31.76 32.48 32.66 33.00 33.10 33.20 33.13 33.07 33.03 33.01 33.01 33.01
      LAYER  9      32.85 32.82 33.45 33.80 33.86 33.97 34.04 33.92 33.77 33.90 33.98 33.98 33.98
      LAYER 10      34.12 34.33 34.78 34.90 35.08 35.15 35.21 35.18 35.18 35.21 35.28 35.27 35.27
      LAYER 11      36.10 36.32 36.60 36.67 36.78 36.83 36.88 36.91 36.93 36.99 37.00 37.01 37.01
      LAYER 12      40.71 40.75 40.77 40.76 40.79 40.79 40.80 40.81 40.81 40.81 40.82 40.82 40.82
   LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP= 2900.00  HRS.        AIR TEMPERATURE= 21.22

                      1     2     3     4     5     6     7     8     9    10    11    12
   UPPER BOUNDARY   22.30 22.30 22.30 22.30 22.30 22.30 21.22 21.22 21.22 21.22 21.22 21.22
      LAYER  1      22.59 22.52 22.68 22.48 22.40 22.41 22.13 22.73 23.43 23.74 23.76 23.76 23.76
      LAYER  2      23.36 23.48 23.88 22.97 22.77 22.90 23.30 24.55 26.32 26.78 26.88 26.88 26.88
      LAYER  3      23.93 24.13 25.29 25.79 25.89 26.62 27.14 27.36 27.80 27.80 27.86 27.89 27.89
      LAYER  4      24.64 24.84 25.77 28.04 30.42 30.74 31.00 30.17 28.64 28.24 28.31 28.32 28.32
      LAYER  5      26.19 26.48 28.84 29.80 31.55 31.75 31.89 31.23 30.33 30.03 30.14 30.14 30.14
      LAYER  6      27.91 28.15 30.44 31.15 32.01 32.20 32.31 31.97 31.54 31.08 31.08 31.08 31.08
      LAYER  7      29.15 29.37 31.45 31.84 32.38 32.54 32.63 32.39 32.28 32.08 32.13 32.14 32.14
      LAYER  8      31.55 31.66 32.34 32.59 32.99 33.06 33.16 33.03 32.98 32.84 32.89 32.89 32.89
      LAYER  9      32.52 32.71 33.33 33.46 33.76 33.85 33.91 33.80 33.85 33.76 33.82 33.83 33.83
      LAYER 10      33.97 34.15 34.64 34.75 34.92 34.99 35.05 35.03 35.01 35.05 35.11 35.12 35.12
      LAYER 11      35.83 36.15 36.43 36.49 36.60 36.68 36.71 36.74 36.78 36.78 36.82 36.84 36.84
      LAYER 12      40.64 40.68 40.71 40.71 40.72 40.73 40.74 40.74 40.74 40.75 40.76 40.76 40.76
   LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP= 3000.00  HRS.        AIR TEMPERATURE= 22.80

                      1     2     3     4     5     6     7     8     9    10    11    12
   UPPER BOUNDARY   23.54 23.54 23.54 23.54 23.54 23.54 22.80 22.80 22.80 22.80 22.80 22.80
      LAYER  1      23.75 23.77 23.82 23.88 23.81 23.81 23.34 23.63 24.42 24.08 24.08 24.08 24.08
      LAYER  2      24.33 24.42 24.80 24.08 23.81 24.01 24.21 25.32 26.73 27.18 27.23 27.23 27.23
      LAYER  3      24.83 24.96 25.96 26.41 27.17 27.37 27.64 27.78 27.84 27.78 27.82 27.82 27.82
      LAYER  4      25.35 25.62 27.20 28.80 30.45 30.76 30.98 30.20 29.00 28.40 28.48 28.48 28.48
      LAYER  5      26.64 26.87 28.98 29.61 31.50 31.76 31.88 31.18 30.38 29.97 30.08 30.08 30.08
      LAYER  6      28.15 28.38 30.41 31.09 31.98 32.15 32.28 31.94 31.46 31.46 31.84 31.84 31.84
      LAYER  7      29.27 29.48 31.34 31.88 32.33 32.47 32.57 32.33 32.16 32.00 32.02 32.02 32.02
      LAYER  8      31.45 31.60 32.24 32.50 32.87 32.99 33.08 32.94 32.87 32.73 32.76 32.77 32.77
      LAYER  9      32.40 32.59 33.21 33.37 33.64 33.73 33.80 33.69 33.64 33.63 33.69 33.70 33.70
      LAYER 10      33.82 34.05 34.50 34.60 34.78 34.85 34.91 34.88 34.86 34.90 34.96 34.97 34.97
      LAYER 11      35.76 35.98 36.27 36.33 36.44 36.49 36.54 36.57 36.59 36.61 36.66 36.67 36.67
      LAYER 12      40.57 40.61 40.64 40.64 40.66 40.66 40.67 40.68 40.68 40.68 40.69 40.69 40.69
   LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP= 3100.00  HRS.        AIR TEMPERATURE= 24.05

                      1     2     3     4     5     6     7     8     9    10    11    12
   UPPER BOUNDARY   24.85 24.85 24.85 24.85 24.85 24.85 24.05 24.05 24.05 24.05 24.05 24.05
      LAYER  4      26.09 26.22 27.65 28.99 30.49 30.76 31.00 30.23 29.18 28.59 28.63 28.63 28.63
      LAYER  5      27.10 27.28 29.11 29.85 31.44 31.70 31.82 31.10 30.37 29.98 30.02 30.03 30.03
      LAYER  6      28.40 28.58 30.38 31.03 31.88 32.11 32.21 31.90 31.43 31.38 31.43 31.43 31.43
      LAYER  7      29.40 29.57 31.26 31.81 32.29 32.42 32.51 32.28 32.12 31.88 31.89 31.89 31.89
      LAYER  8      31.35 31.52 32.15 32.41 32.80 32.92 33.00 32.88 32.79 32.67 32.68 32.68 32.68
      LAYER  9      32.27 32.49 33.10 33.28 33.54 33.63 33.70 33.58 33.44 33.53 33.57 33.58 33.58
      LAYER 10      33.68 33.91 34.37 34.47 34.65 34.72 34.77 34.75 34.73 34.76 34.81 34.83 34.83
      LAYER 11      35.61 35.83 36.11 36.17 36.28 36.34 36.39 36.42 36.43 36.46 36.51 36.52 36.52
      LAYER 12      40.50 40.54 40.57 40.58 40.59 40.60 40.60 40.61 40.61 40.62 40.63 40.63 40.63
   LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP= 3200.00  HRS.        AIR TEMPERATURE= 25.57

                      1     2     3     4     5     6     7     8     9    10    11    12
   UPPER BOUNDARY   26.21 26.21 26.21 26.21 26.21 26.21 25.57 25.57 25.57 25.57 25.57 25.57
      LAYER  1      26.21 26.23 26.28 26.22 26.20 26.20 25.95 26.17 26.53 26.64 26.65 26.65 26.65
      LAYER  2      26.35 26.41 26.73 26.34 26.34 26.37 26.47 26.82 27.79 27.97 28.00 28.00 28.00
      LAYER  3      26.86 26.94 27.38 27.74 28.43 28.58 28.73 28.59 28.54 28.30 28.39 28.39 28.39
      LAYER  4      26.81 26.92 28.11 29.16 30.84 30.82 31.02 30.28 29.37 28.79 28.82 28.82 28.82
      LAYER  5      27.55 27.71 29.27 29.92 31.39 31.66 31.79 31.06 30.41 29.98 30.01 30.02 30.02
      LAYER  6      28.64 28.81 30.41 30.96 31.95 32.07 32.16 31.86 31.39 31.27 31.34 31.34 31.34
      LAYER  7      29.53 29.69 31.19 31.74 32.24 32.37 32.45 32.22 32.06 31.95 31.97 31.97 31.97
      LAYER  8      31.26 31.45 32.08 32.33 32.73 32.84 32.82 32.78 32.72 32.61 32.63 32.63 32.63
      LAYER  9      32.16 32.38 33.00 33.16 33.44 33.53 33.60 33.49 33.38 33.44 33.48 33.49 33.49
      LAYER 10      33.54 33.79 34.24 34.34 34.52 34.59 34.65 34.63 34.61 34.64 34.69 34.70 34.70
      LAYER 11      35.46 35.69 35.97 36.03 36.14 36.19 36.25 36.28 36.29 36.31 36.35 36.36 36.36
      LAYER 12      40.43 40.48 40.50 40.51 40.52 40.53 40.54 40.54 40.55 40.55 40.56 40.57 40.57
   LOWER BOUNDARY   39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00 39.00


        TIME AT THIS STEP= 3300.00  HRS.        AIR TEMPERATURE= 27.13

                      1     2     3     4     5     6     7     8     9    10    11    12
```

```
UPPER BOUNDARY   27.82 27.82 27.82 27.82 27.82 27.82 27.13 27.13 27.13 27.13 27.13 27.13
  LAYER   1      27.48 27.50 27.56 27.53 27.58 27.58 27.31 27.37 27.63 27.66 27.69 27.66 27.69
  LAYER   2      27.34 27.36 27.67 27.46 27.83 27.61 27.60 27.69 28.33 28.39 28.40 28.40 28.40
  LAYER   3      27.36 27.46 28.07 28.41 29.10 29.22 29.31 29.01 28.88 28.67 28.68 28.88 28.88
  LAYER   4      27.40 27.58 28.88 29.29 30.80 30.87 31.04 30.36 29.56 29.01 29.02 29.02 29.02
  LAYER   5      27.87 28.11 28.64 30.00 31.35 31.62 31.78 31.03 30.46 30.00 30.03 30.03 30.03
  LAYER   6      28.66 29.03 30.43 30.95 31.93 32.02 32.11 31.61 31.36 31.21 31.28 31.27 31.27
  LAYER   7      29.85 29.61 31.14 31.88 32.20 32.21 32.30 32.16 32.01 31.92 31.94 31.94 31.94
  LAYER   8      31.16 31.36 32.00 32.35 32.88 32.77 32.89 32.72 32.66 32.56 32.58 32.58 32.58
  LAYER   9      32.05 32.29 32.90 33.06 33.38 33.44 33.51 33.40 33.27 33.36 33.40 33.41 33.41
  LAYER  10      33.43 33.87 34.12 34.23 34.41 34.48 34.54 34.52 34.50 34.63 34.67 34.68 34.69
  LAYER  11      35.32 35.55 35.83 35.89 36.00 36.06 36.11 36.14 36.15 36.18 36.22 36.24 36.24
  LAYER  12      40.36 40.41 40.44 40.44 40.46 40.46 40.47 40.46 40.48 40.48 40.50 40.50 40.50
LOWER BOUNDARY   38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


        TIME AT THIS STEP= 3400.00  HRS.          AIR TEMPERATURE= 28.74

  LAYER   2      28.25 28.30 28.56 28.51 28.80 28.68 28.74 28.42 28.82 29.00 28.96 28.90 28.90
  LAYER   3      28.14 28.20 28.72 29.04 29.78 29.88 29.90 29.41 28.24 28.09 28.08 28.99 28.99
  LAYER   4      28.10 28.18 28.98 29.58 30.67 30.82 31.08 30.42 29.78 29.23 29.23 29.23 29.23
  LAYER   5      28.35 28.47 29.61 30.08 31.32 31.58 31.73 31.02 30.52 30.08 30.07 30.07 30.07
  LAYER   6      29.09 29.23 30.47 30.94 31.88 32.00 32.07 31.77 31.34 31.18 31.21 31.21 31.21
  LAYER   7      29.78 29.92 31.11 31.80 32.18 32.27 32.34 32.13 32.00 31.86 31.90 31.91 31.91
  LAYER   8      31.11 31.32 31.99 32.20 32.60 32.71 32.78 32.66 32.60 32.50 32.52 32.53 32.53
  LAYER   9      32.00 32.20 32.84 32.99 33.27 33.30 33.43 33.33 33.20 33.28 33.32 33.34 33.34
  LAYER  10      33.30 33.58 34.02 34.[illegible] 34.30 34.37 34.43 34.41 34.39 34.43 34.47 34.48 34.48
  LAYER  11      35.16 35.42 35.70 35.77 35.88 35.93 35.98 36.01 36.03 36.06 36.10 36.11 36.11
  LAYER  12      40.30 40.34 40.37 40.38 40.38 40.40 40.41 40.41 40.42 40.42 40.43 40.44 40.44
LOWER BOUNDARY   38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


        TIME AT THIS STEP= 3500.00  HRS.          AIR TEMPERATURE= 30.36

                   1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY   30.53 30.53 30.53 30.53 30.53 30.53 30.36 30.36 30.36 30.36 30.36 30.36
  LAYER   1      30.02 30.03 30.10 30.13 30.32 30.31 30.11 29.75 29.64 29.61 29.60 29.61 29.61
  LAYER   2      29.10 29.13 29.37 29.46 30.16 30.12 29.89 29.06 29.20 29.20 29.19 29.20 29.20
  LAYER   3      28.82 28.67 29.30 29.61 30.45 30.64 30.49 29.75 29.55 29.29 29.26 29.26 29.26
  LAYER   4      28.65 28.71 29.38 29.79 30.75 30.96 31.12 30.49 29.94 29.45 29.44 29.44 29.44
  LAYER   5      28.59 28.80 29.78 30.17 31.29 31.58 31.70 31.02 30.59 30.12 30.12 30.12 30.12
  LAYER   6      29.29 29.42 30.82 30.94 31.86 31.96 32.03 31.73 31.33 31.13 31.17 31.17 31.17
  LAYER   7      29.87 30.02 31.10 31.54 32.11 32.23 32.29 32.06 31.99 31.83 31.86 31.86 31.86
  LAYER   8      31.05 31.26 31.86 32.15 32.55 32.65 32.73 32.61 32.56 32.44 32.47 32.47 32.47
  LAYER   9      31.99 32.13 32.77 32.92 33.20 33.29 33.35 33.26 33.14 33.22 33.26 33.26 33.26
  LAYER  10      33.22 33.46 33.92 34.02 34.20 34.27 34.33 34.32 34.30 34.33 34.37 34.38 34.38
  LAYER  11      35.06 35.30 35.56 35.65 35.79 35.81 35.86 35.90 35.91 35.93 35.98 35.99 35.99
  LAYER  12      40.23 40.27 40.30 40.31 40.32 40.33 40.34 40.35 40.35 40.36 40.37 40.37 40.37
LOWER BOUNDARY   38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00


        TIME AT THIS STEP= 3600.00  HRS.          AIR TEMPERATURE= 32.00

                   1     2     3     4     5     6     7     8     9    10    11    12
UPPER BOUNDARY   32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00 32.00
  LAYER   1      31.23 31.24 31.31 31.36 31.64 31.64 31.52 30.93 30.94 30.88 30.87 30.87 30.87
  LAYER   2      29.83 29.85 30.07 30.24 31.41 31.39 31.02 29.86 29.72 29.59 29.58 29.58 29.58
  LAYER   3      29.40 29.44 29.80 30.10 31.10 31.18 31.08 30.12 29.88 29.58 29.57 29.57 29.57
  LAYER   4      29.12 29.17 29.70 29.97 30.83 31.04 31.17 30.56 30.11 29.66 29.64 29.64 29.64
  LAYER   5      28.99 29.09 29.93 30.29 31.28 31.53 31.68 31.02 30.66 30.19 30.18 30.18 30.18
  LAYER   6      29.46 29.59 30.57 30.86 31.63 31.97 32.00 31.68 31.33 31.13 31.14 31.15 31.15
  LAYER   7      29.98 30.11 31.10 31.49 32.07 32.19 32.25 32.04 31.97 31.79 31.82 31.83 31.83
  LAYER   8      31.00 31.22 31.86 32.10 32.48 32.60 32.67 32.56 32.52 32.39 32.41 32.42 32.42
  LAYER   9      31.89 32.08 32.71 32.88 33.13 33.22 33.28 33.18 33.08 33.15 33.18 33.19 33.19
  LAYER  10      33.16 33.37 33.83 33.93 34.11 34.18 34.24 34.23 34.21 34.24 34.28 34.30 34.30
  LAYER  11      34.95 35.19 35.47 35.54 35.65 35.70 35.75 35.79 35.80 35.82 35.87 35.88 35.88
  LAYER  12      40.18 40.21 40.24 40.24 40.26 40.27 40.27 40.28 40.29 40.29 40.31 40.31 40.31
LOWER BOUNDARY   38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00 38.00
```

```
C     **************************************************
C     *                                                *
C     *          THIS PROGRAM CONVERTS THE OUTPUT      *
C     *      FROM DAMIN(TWO DIMENSIONAL HEAT FLOW)     *
C     *      TO THE INPUT USED FOR MO. THE PROGRAM     *
C     *       USED TO CALCULATE FROST HEAVE            *
C     *                                                *
C     *                                                *
C     **************************************************
      DIMENSION T(12,12)
      CHARACTER FLAG*4,TEST*4
      TEST=' UPR'
      N=0
   20 READ (5,1) FLAG
      IF (FLAG.EQ.TEST) GO TO 30
      IF (N.GT.2000) GO TO 40
      N=N+1
      GO TO 20
   30 DO 100 NLAY=1,12
         READ (5,2) (T(NCOL,NLAY), NCOL=1,12)
         WRITE (6,3) (T(NCOL,NLAY), NCOL=1,12)
  100 CONTINUE
      GO TO 20
   40 WRITE (6,4) N,FLAG
    1 FORMAT (A4)
    2 FORMAT (17X,12F6.2)
    3 FORMAT (F8.2,11F6.2)
    4 FORMAT (I5,A4)
      END
```

```
C*******************************************************************
C
C
C        PROGRAM TO ESTIMATE FROST HEAVE FROM THE TEMPERATURE
C        DISTRIBUTION SOLVED BY THE TWO DIMENSIONAL CASE.
C
C*******************************************************************
C
C   T      - TEMPERATURE DISTRIBUTION
C   Z      - HIEGHT OF ELEMENT
C   NCOL   - COLUMN OF GRID ANALYZING
C   SPO    - SEGREGATION POTENTIAL AT ZERO OVERBURDEN
C   SPX    - SEGREGATION POTENTIAL AT AN OVERBURDEN PRESSURE
C   DTOUT  - LENGTH OF TIME STEP
C   DF     - DEPTH OF FOOTING
C   CF     - THERMAL CONDUCTIVITY OF FROZEN SOIL
C   CFR    - THERMAL CONDUCTIVITY OF FROZEN FRINGE
C   INS    - COUNTER = 0 if no insulation
C                    = 1 if layer 3 is insulated
C                    = 2 if layer 5 is insulated
C   HV     - SEGREGATIONAL HEAVE FOR THE TIME STEP
C   HVS    - TOTAL SEGREGATIONAL HEAVE
C   HVT    - TOTAL SEGREGATIONAL HEAVE AND INSITU HEAVE
C   XPM    - FROST PENETRATION
C   TTIME  - LENGTH OF FREEZING SEASON
C
C**********************************************************************
C
C
      DIMENSION T(12,12),Z(12),DF(12),INS(12),HVT(12),HVS(12)
      CHARACTER*72 COMENT
      READ(5,13) COMENT
      READ(5,11) SPO,DTOUT,CF,CFR,TTIME,WC
      READ(5,10) (Z(N), N=1,12)
      READ(5,12) (INS(N), N=1,12)
      READ(5,10) (DF(N), N=1,12)
      WRITE(6,13) COMENT
      WRITE(6,17) SPO
      WRITE(6,14) (Z(N), N=1,12)
      WRITE(6,15) (INS(N), N=1,12)
      WRITE(6,16) (DF(N), N=1,12)
      WRITE(7,13) COMENT
      WRITE(6,20)
      WRITE(7,24)
      DO 50 N=1,12
      Z(N)=Z(N)/12.0
      HVS(N)=0.0
      HVT(N)=0.0
   50 CONTINUE
      TIME=-100.0
   10 FORMAT(F6.2,11F6.2)
   11 FORMAT(6F8.3)
   12 FORMAT(12I2)
   13 FORMAT(A72)
   14 FORMAT(' LAYER THICKNESS',/,' ',12F6.2)
   15 FORMAT(/,' COUNTER TO START HEAVE, 0=NO INSULATION',
     1 '1=INSULATION @ LAYER 3, 2=INSULATION @ LAYER 5',/,
     1 ' COLUMN      1     2     3     4     5     6     7     8',
     1 '     9    10    11    12',/,
     1 '          ',12I6)
   16 FORMAT(' FOOTING DEPTH(MM)',/'          ',12F6.1)
   17 FORMAT(//' SPo = ',F12.7)
C                  ..................READ TEMPERATURE DISTRIBUTION
 1000 TIME=TIME+DTOUT
      IF (TIME.GT.TTIME) GO TO 9999
      DO 100 NLAY=1,12
      READ(5,10) (T(NCOL,NLAY), NCOL=1,12)
  100 CONTINUE
C                  ..................STOP IF TIME LONGER THAN FREEZING SEASON
  888 DO 5000 NCOL=1,12
C
C                         ..................PROGRAM DOES NOT CALCULATE
C                         ..................FROST PENTETATION UNTIL 3RD
C                         ..................ELEMENT IS FROZEN
C
      IF (T(NCOL,2).GT.31.9) GO TO 5000
C*********************************************************************
C
C  CALCUTLATE FROST PENETRATION
C
C*********************************************************************
      DO 555 NX=3,12
      IF (T(NCOL,NX).GT.31.9) GO TO 441
  555 CONTINUE
  441 T1=T(NCOL,(NX-1))
      T2=T(NCOL,(NX))
      X1=Z(NX-1)/2
      X2=Z(NX)/2+Z(NX-1)
      XP=X1-((((X1-X2)/(T1-T2)))*(T1-32.0))
C
C                    ..................ADD FROST PENETRATION FROM EACH ELEMENT
C
      IF (NX.EQ.3) GO TO 446
      IF (NX.EQ.4) GO TO 442
      IF (NX.GT.4) GO TO 443
  442 XP=XP+Z(2)
      GO TO 446
  443 NX2=NX-2
      DO 445 NP=2,NX2
      XP=XP+Z(NP)
  445 CONTINUE
C                     ....................FROST PENETRATION IN MM.
  446 XPM=XP*304.8
C                     ....................FROST PENETRATION IN INCHES.
      XP=XP*12.0
C*****************************************************************
C
C    CALCULATE SEGREGATIONAL HEAVE
C
C*****************************************************************
      IF (INS(NCOL).EQ.0) NWS=2
      IF (INS(NCOL).EQ.1) NWS=4
      IF (INS(NCOL).EQ.2) NWS=7
      IF (T(NCOL,NWS).GT.32.0) GO TO 434
      IF (INS(NCOL).NE.1) GO TO 460
      IF (NX.GT.5) GO TO 460
      DERTF=2*((T(NCOL,5)-T(NCOL,4))/(Z(5)-Z(4)))
      GO TO 111
  460 TM1=T(NCOL,(NX-1))
      TM2=T(NCOL,(NX-2))
      ZM1=Z(NX-1)/2
      ZM2=Z(NX-2)/2
      DERTF=(TM1-TM2)/(ZM1+ZM2)
      IF (INS(NCOL).NE.2) GO TO 111
      IF (NX.GT.6) GO TO 111
      TM1=T(NCOL,6)
      TM2=T(NCOL,7)
      DERTF=2*(TM1-TM2)/(Z(6)+Z(7))
  111 DERTF=DERTF*0.5555/304.8
C                     ....................REDUCTION SP FOR OVERBURDEN PRESSURE
      PE=XPM*.020*0.001
      SPX=SPO*(EXP(PE*(-6.86)))
      GRADT=CF*DERTF/(SPX*75.6*CFR)
      V=SPX*GRADT
      HV=1.09*V*DTOUT*3600.
      HVS(NCOL)=HV+HVS(NCOL)
C*******************************************************************
C
C   CALCULATE INSITU HEAVE
C
C*******************************************************************
  434 VOID=2.65*WC/100.
      POR=VOID/(VOID+1)
      XS=XPM-DP(NCOL)
      HVI=0.09*0.90*POR*XS
      IF (HVI.LT.0.0) HVI=0.0
C
C     CALCULATE TOTAL HEAVE
C
      HVT(NCOL)=HVI+HVS(NCOL)
C*****************************************************************
C
C        PRINT OUTPUT
C
C*****************************************************************
   20 FORMAT(///,'    TIME  COLUMN  FROST PEN. DERTF     GRADT     ',
     1 ' SPX       SEG    TOT-SEG  TOTAL',//)
      WRITE(6,21)TIME,NCOL,XPM,DERTF,GRADT,SPX,HV,HVS(NCOL),
     1 HVT(NCOL)
   21 FORMAT(' ',F8.2,4X,I4,F8.2,2E10.3,3F8.2)
 5000 CONTINUE
      WRITE(7,23) TIME
      WRITE(7,22) (HVS(NCOL), NCOL=1,12)
 5001 CONTINUE
      WRITE(7,24)
      WRITE(7,22) (HVT(NCOL), NCOL=1,12)
 5002 CONTINUE
   22 FORMAT(12F8.2)
   23 FORMAT(///,10X,'TIME = ',F10.2,/,10X,'SEGREGATIONAL HEAVE   ')
   24 FORMAT(/,10X,'TOTAL HEAVE')
      GO TO 1000
 9999 END
```

OUTPUT FROM THE TWO DIMENSIONAL FROST HEAVE PROGRAM

```
SPo =    0.0012000
LAYER THICKNESS
  6.00  6.00  2.00  6.00 12.00  6.00  6.00 12.00 12.00 24.00 36.00200.00

COUNTER TO START HEAVE, 0=NO INSULATION1=INSULATION @ LAYER 3, 2=INSULATION @ LAYER 8
COLUMN      1      2      3      4      5      6      7      8      9     10     11     12
            0      0      0      1      1      1      1      1      0      0      0      0
FOOTING DEPTH(MM)
          0.0    0.0    0.0  200.0  200.0  200.0  200.0  200.0    0.0    0.0    0.0    0.0


   TIME   COLUMN  FROST PEN. DERTF      GRADT      SPX          SEG    TOT-SEG  TOTAL

   300.00       1     99.80 0.840E-02 0.839E-02 0.116E-02     3.83     3.83     7.41
   300.00       2     98.33 0.844E-02 0.831E-02 0.116E-02     3.85     3.85     7.37
   300.00       3     83.83 0.878E-02 0.881E-02 0.116E-02     4.00     4.00     7.00
   300.00       4     98.74 0.878E-02 0.881E-02 0.116E-02     4.00     0.0      0.0
   300.00       5    147.23 0.878E-02 0.881E-02 0.116E-02     4.00     0.0      0.0
   300.00       6    141.56 0.878E-02 0.881E-02 0.116E-02     4.00     0.0      0.0
   300.00       7    122.64 0.878E-02 0.881E-02 0.116E-02     4.00     0.0      0.0
   400.00       1    152.85 0.114E-01 0.101E-01 0.117E-02     4.81     8.44    13.83
   400.00       2    148.62 0.114E-01 0.101E-01 0.117E-02     4.81     8.48    13.78
   400.00       3    108.40 0.121E-01 0.106E-01 0.116E-02     4.81     8.80    12.83
   400.00       4    129.40 0.121E-01 0.106E-01 0.116E-02     4.81     0.0      0.0
   400.00       5    188.81 0.121E-01 0.106E-01 0.116E-02     4.81     0.0      0.0
   400.00       6    182.85 0.121E-01 0.106E-01 0.116E-02     4.81     0.0      0.0
   400.00       7    144.71 0.121E-01 0.106E-01 0.116E-02     4.81     0.0      0.0
   400.00       8     81.88 0.121E-01 0.106E-01 0.116E-02     4.81     0.0      0.0
   500.00       1    188.37 0.771E-02 0.881E-02 0.116E-02     3.10    11.84    18.59
   500.00       2    182.62 0.771E-02 0.881E-02 0.116E-02     3.10    11.88    18.47
   500.00       3    175.88 0.127E-01 0.113E-01 0.116E-02     5.14    14.04    20.35
   500.00       4    183.76 0.127E-01 0.113E-01 0.116E-02     5.14     0.0      0.0
   500.00       5    188.65 0.127E-01 0.113E-01 0.116E-02     5.14     0.0      0.0
   500.00       6    182.82 0.127E-01 0.113E-01 0.116E-02     5.14     0.0      0.0
   500.00       7    184.77 0.127E-01 0.113E-01 0.116E-02     5.14     0.0      0.0
   500.00       8     91.88 0.127E-01 0.113E-01 0.116E-02     5.14     0.0      0.0
   600.00       1    278.40 0.108E-01 0.884E-02 0.114E-02     4.27    15.81    25.84
   600.00       2    275.86 0.108E-01 0.884E-02 0.114E-02     4.32    15.88    25.80
   600.00       3    227.04 0.168E-01 0.148E-01 0.115E-02     6.71    20.75    28.80
   600.00       4    218.79 0.168E-01 0.148E-01 0.115E-02     6.71     0.0      0.67
   600.00       5    208.86 0.168E-01 0.148E-01 0.115E-02     6.71     0.0      0.31
   600.00       6    200.50 0.168E-01 0.148E-01 0.115E-02     6.71     0.0      0.02
   600.00       7    183.22 0.168E-01 0.148E-01 0.115E-02     6.71     0.0      0.0
   600.00       8    107.55 0.168E-01 0.148E-01 0.115E-02     6.71     0.0      0.0
   600.00      10     87.48 0.163E-01 0.143E-01 0.116E-02     6.85     6.85     8.78
   600.00      11     91.25 0.162E-01 0.143E-01 0.116E-02     6.82     6.82     8.88
   600.00      12     91.25 0.162E-01 0.143E-01 0.116E-02     6.82     6.82     8.88
   700.00       1    305.35 0.144E-01 0.128E-01 0.114E-02     5.71    21.52    32.47
   700.00       2    301.67 0.145E-01 0.128E-01 0.114E-02     5.73    21.81    32.43
   700.00       3    281.79 0.142E-01 0.125E-01 0.114E-02     5.82    26.37    38.48
   700.00       7    200.00 0.142E-01 0.125E-01 0.114E-02     5.82     0.0      0.0
   700.00       8    130.81 0.142E-01 0.125E-01 0.114E-02     5.82     0.0      0.0
   700.00       9     88.58 0.188E-01 0.164E-01 0.118E-02     7.80     7.80    10.81
   700.00      10    105.05 0.184E-01 0.162E-01 0.116E-02     7.48    14.14    17.91
   700.00      11    113.76 0.183E-01 0.161E-01 0.118E-02     7.45    14.06    18.15
   700.00      12    114.64 0.183E-01 0.161E-01 0.116E-02     7.43    14.05    18.15
   800.00       1    370.84 0.154E-01 0.136E-01 0.112E-02     8.01    27.53    40.84
   800.00       2    363.08 0.155E-01 0.137E-01 0.112E-02     8.08    27.57    40.70
   800.00       3    318.25 0.195E-01 0.173E-01 0.113E-02     7.88    34.08    46.47
   800.00       4    287.00 0.195E-01 0.173E-01 0.113E-02     7.88     0.0      2.04
   800.00       5    239.88 0.195E-01 0.173E-01 0.113E-02     7.88     0.0      1.43
   800.00       6    230.82 0.195E-01 0.173E-01 0.112E-02     7.86     0.0      1.11
   800.00       7    218.55 0.195E-01 0.173E-01 0.113E-02     7.88     0.0      0.58
   800.00       8    164.13 0.195E-01 0.173E-01 0.113E-02     7.88     0.0      0.0
   800.00       9    114.20 0.203E-01 0.178E-01 0.118E-02     8.27    18.87    19.87
   800.00      10    128.02 0.203E-01 0.176E-01 0.117E-02     8.18    22.32    27.17
   800.00      11    148.82 0.201E-01 0.177E-01 0.117E-02     8.11    22.18    27.55
   800.00      12    150.91 0.201E-01 0.177E-01 0.117E-02     8.11    22.18    27.58
   900.00       1    474.08 0.142E-01 0.127E-01 0.110E-02     5.48    33.01    50.02
   900.00       2    459.32 0.144E-01 0.128E-01 0.111E-02     5.56    33.25    48.72
   900.00       3    378.53 0.180E-01 0.168E-01 0.112E-02     7.42    41.47    54.88
   900.00       4    271.00 0.180E-01 0.168E-01 0.112E-02     7.42     0.0      2.88
   900.00       5    252.72 0.180E-01 0.168E-01 0.112E-02     7.42     0.0      1.89
   900.00       6    244.10 0.180E-01 0.168E-01 0.112E-02     7.42     0.0      1.56
   900.00       7    231.14 0.180E-01 0.168E-01 0.112E-02     7.42     0.0      1.12
   900.00       8    207.56 0.180E-01 0.168E-01 0.112E-02     7.42     0.0      0.27
   900.00       9    167.47 0.213E-01 0.188E-01 0.116E-02     8.80    24.47    30.48
   900.00      10    177.80 0.217E-01 0.191E-01 0.116E-02     8.72    21.05    37.42
   900.00      11    181.86 0.215E-01 0.190E-01 0.116E-02     8.64    30.82    37.34
   900.00      12    181.88 0.215E-01 0.190E-01 0.116E-02     8.64    30.80    37.32
  1000.00       1    510.55 0.112E-01 0.988E-02 0.110E-02     4.27    37.29    55.61
  1000.00       2    510.21 0.114E-01 0.101E-01 0.110E-02     4.38    37.81    55.81
  1000.00       3    480.53 0.171E-01 0.152E-01 0.111E-02     5.81    48.06    64.80
  1000.00       4    279.78 0.112E-01 0.988E-02 0.114E-02     4.43     4.43     7.39
  1000.00       5    264.63 0.112E-01 0.988E-02 0.114E-02     4.43     0.0      3.32
  1000.00       6    266.57 0.112E-01 0.988E-02 0.114E-02     4.43     0.0      2.03
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1000.00      7   246.78 0.113E-01 0.888E-02 0.114E-02     4.43    0.0     1.84
1000.00      8   238.18 0.113E-01 0.888E-02 0.114E-02     4.43    0.0     1.38
1000.00      9   204.14 0.113E-01 0.100E-01 0.118E-02     4.54   28.01   38.33
1000.00     10   188.38 0.525E-02 0.464E-02 0.118E-02     2.11   33.18   40.27
1000.00     11   212.18 0.525E-02 0.464E-02 0.118E-02     2.10   32.82   40.53
1000.00     12   213.88 0.525E-02 0.464E-02 0.118E-02     2.10   32.81   40.57
1100.00      1   540.44 0.138E-01 0.123E-01 0.108E-02     5.25   42.53   61.92
1100.00      2   535.84 0.138E-01 0.123E-01 0.108E-02     5.25   42.88   62.08
1100.00      3   508.52 0.158E-01 0.138E-01 0.110E-02     5.97   54.08   72.28
1100.00      4   313.18 0.838E-02 0.743E-02 0.113E-02     3.31    7.74   11.80
1100.00      5   274.38 0.838E-02 0.743E-02 0.113E-02     3.31    0.0     2.87
1100.00      6   267.31 0.838E-02 0.743E-02 0.113E-02     3.31    0.0     2.41
1100.00      7   268.14 0.838E-02 0.743E-02 0.113E-02     3.31    0.0     2.08
1100.00      8   265.31 0.838E-02 0.743E-02 0.113E-02     3.31    0.0     1.98
1100.00      9   278.40 0.121E-01 0.108E-01 0.114E-02     4.82   33.63   43.85
1100.00     10   247.92 0.588E-02 0.527E-02 0.118E-02     2.38   35.58   44.42
1100.00     11   258.34 0.568E-02 0.504E-02 0.114E-02     2.28   35.18   44.74
1100.00     12   259.09 0.568E-02 0.504E-02 0.114E-02     2.28   35.17   44.82
1200.00      1   580.58 0.140E-01 0.125E-01 0.108E-02     5.32   47.85   68.88
1200.00      2   572.64 0.140E-01 0.125E-01 0.108E-02     5.33   48.19   68.73
1200.00      3   510.84 0.164E-01 0.146E-01 0.110E-02     6.39   60.34   78.87
1200.00      4   364.81 0.802E-02 0.712E-02 0.112E-02     3.14   10.88   18.76
1200.00      5   288.82 0.101E-01 0.891E-02 0.114E-02     3.98    0.0     2.47
1200.00      9   308.15 0.154E-01 0.138E-01 0.114E-02     6.07   39.90   50.95
1200.00     10   281.38 0.651E-02 0.576E-02 0.114E-02     2.56   36.11   46.20
1200.00     11   283.16 0.629E-02 0.557E-02 0.114E-02     2.49   37.86   47.84
1200.00     12   283.13 0.634E-02 0.562E-02 0.114E-02     2.53   37.88   47.64
1300.00      1   628.91 0.140E-01 0.125E-01 0.107E-02     5.26   53.11   75.06
1300.00      2   624.77 0.140E-01 0.125E-01 0.107E-02     5.26   53.47   75.89
1300.00      3   520.58 0.117E-01 0.104E-01 0.108E-02     4.47   64.80   83.84
1300.00      4   421.28 0.848E-02 0.752E-02 0.111E-02     3.28   14.18   22.10
1300.00      5   280.12 0.852E-02 0.756E-02 0.114E-02     3.38    7.36   10.26
1300.00      6   278.58 0.955E-02 0.846E-02 0.114E-02     3.78    3.78    6.64
1300.00      7   277.83 0.955E-02 0.846E-02 0.114E-02     3.79    0.0     2.79
1300.00      8   278.77 0.955E-02 0.846E-02 0.114E-02     3.79    0.0     2.63
1300.00      9   385.90 0.153E-01 0.136E-01 0.112E-02     6.00   45.89   59.01
1300.00     10   305.18 0.828E-02 0.722E-02 0.114E-02     3.28   41.37   52.32
1300.00     11   309.07 0.798E-02 0.708E-02 0.114E-02     3.15   40.83   51.52
1300.00     12   308.38 0.804E-02 0.713E-02 0.114E-02     3.17   40.88   51.88
1400.00      1   712.17 0.137E-01 0.123E-01 0.106E-02     5.10   58.21   83.78
1400.00      2   681.88 0.136E-01 0.124E-01 0.106E-02     5.15   58.82   83.43
1400.00      3   684.65 0.120E-01 0.107E-01 0.108E-02     4.58   69.36   88.28
1400.00      4   477.84 0.933E-02 0.821E-02 0.110E-02     3.59   17.78   27.72
1400.00      5   303.81 0.751E-02 0.666E-02 0.114E-02     2.97   10.34   14.07
1400.00      6   280.13 0.802E-02 0.710E-02 0.114E-02     3.18    6.97    8.85
1400.00      7   279.55 0.831E-02 0.736E-02 0.114E-02     3.30    3.30    6.15
1400.00      8   280.00 0.714E-02 0.633E-02 0.114E-02     2.83    2.83    5.70
1400.00      9   438.03 0.147E-01 0.131E-01 0.111E-02     5.70   61.59   67.24
1400.00     10   350.64 0.980E-02 0.879E-02 0.113E-02     3.89   45.26   57.85
1400.00     11   350.28 0.935E-02 0.830E-02 0.113E-02     3.67   44.50   57.07
1400.00     12   352.06 0.935E-02 0.830E-02 0.113E-02     3.67   44.53   57.18
1500.00      1   740.54 0.122E-01 0.118E-01 0.108E-02     4.89   63.10   88.67
1500.00      2   737.98 0.123E-01 0.120E-01 0.108E-02     4.93   63.85   90.03
1500.00      3   689.17 0.122E-01 0.109E-01 0.108E-02     4.60   73.88   95.09
1500.00      4   505.45 0.115E-01 0.102E-01 0.110E-02     4.42   22.17   33.27
1500.00      5   325.10 0.578E-02 0.601E-02 0.113E-02     2.67   13.02   17.84
1500.00      6   304.80 0.722E-02 0.640E-02 0.114E-02     2.85    9.82   13.58
1500.00      7   280.00 0.736E-02 0.652E-02 0.114E-02     2.92    5.22    8.09
1500.00      8   305.71 0.569E-02 0.504E-02 0.114E-02     2.25    5.08    8.98
1500.00      9   502.89 0.138E-01 0.123E-01 0.110E-02     5.31   58.30   74.84
1500.00     10   420.08 0.906E-02 0.885E-02 0.111E-02     3.67   49.13   64.20
1500.00     11   411.02 0.951E-02 0.848E-02 0.111E-02     3.70   48.20   62.95
1500.00     12   412.79 0.951E-02 0.848E-02 0.111E-02     3.70   48.23   63.03
1600.00      1   761.37 0.612E-02 0.550E-02 0.105E-02     2.29   65.36   92.88
1600.00      2   784.53 0.581E-02 0.522E-02 0.105E-02     2.15   65.70   92.77
1600.00      3   826.08 0.123E-01 0.110E-01 0.107E-02     4.62   76.58  101.11
1600.00      4   512.44 0.150E-01 0.134E-01 0.109E-02     5.75   27.83   39.13
1600.00      5   363.89 0.648E-02 0.575E-02 0.113E-02     2.55   15.56   21.08
1600.00      6   324.12 0.671E-02 0.595E-02 0.113E-02     2.64   12.47   18.92
1600.00      7   280.56 0.658E-02 0.581E-02 0.114E-02     2.60    8.82   11.71
1600.00      8   348.08 0.525E-02 0.465E-02 0.113E-02     2.08    7.14   12.38
1600.00      9   613.10 0.135E-01 0.120E-01 0.108E-02     5.18   62.08   80.46
1600.00     10   503.17 0.924E-02 0.824E-02 0.110E-02     3.55   52.87   70.72
1600.00     11   486.82 0.902E-02 0.804E-02 0.110E-02     3.47   51.67   69.13
1600.00     12   488.91 0.897E-02 0.795E-02 0.110E-02     3.46   51.88   69.28
1700.00      1   804.99 0.880E-02 0.774E-02 0.104E-02     3.15   68.52   97.40
1700.00      2   788.84 0.814E-02 0.732E-02 0.104E-02     3.09   68.83   98.86
1700.00      3   873.54 0.122E-01 0.110E-01 0.108E-02     4.57   83.15  107.21
1700.00      4   635.71 0.586E-02 0.523E-02 0.109E-02     2.24   30.18   42.21
1700.00      5   388.38 0.627E-02 0.557E-02 0.112E-02     2.46   18.01   24.77
1700.00      9   641.73 0.598E-02 0.531E-02 0.109E-02     2.27   64.33   83.76
1700.00     10   611.13 0.847E-02 0.756E-02 0.110E-02     3.25   55.82   74.28
1700.00     11   610.33 0.831E-02 0.741E-02 0.110E-02     3.19   54.86   73.17
1700.00     12   610.31 0.829E-02 0.736E-02 0.110E-02     3.18   54.64   73.38
1800.00      1   881.48 0.102E-01 0.922E-02 0.102E-02     3.71   72.23  103.85
1800.00      2   854.11 0.981E-02 0.893E-02 0.103E-02     3.61   72.30  102.84
1800.00      3   724.65 0.119E-01 0.107E-01 0.105E-02     4.42   87.57  113.98
1800.00      4   587.07 0.628E-02 0.562E-02 0.108E-02     2.39   32.55   48.72
1800.00      5   428.06 0.612E-02 0.548E-02 0.111E-02     2.38   20.39   28.80
1800.00      6   381.00 0.580E-02 0.525E-02 0.112E-02     2.31   17.24   23.73
1800.00      7   337.21 0.547E-02 0.485E-02 0.113E-02     2.15   13.33   18.28
1800.00      8   451.86 0.503E-02 0.448E-02 0.111E-02     1.95   11.08   20.11
1800.00      9   577.15 0.627E-02 0.550E-02 0.108E-02     2.38   65.71   87.41
1800.00     10   614.04 0.793E-02 0.707E-02 0.108E-02     3.04   58.96   77.42
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1800.00	11	513.74	0.770E-02	0.592E-02	0.100E-02	2.97	57.63	75.28
1800.00	12	513.72	0.770E-02	0.592E-02	0.100E-02	2.97	57.61	75.24
1900.00	1	893.45	0.900E-02	0.698E-02	0.102E-02	3.80	75.83	107.86
1900.00	2	881.56	0.904E-02	0.687E-02	0.102E-02	3.88	75.88	107.84
1900.00	3	740.27	0.113E-01	0.101E-01	0.105E-02	4.18	61.75	118.31
1900.00	4	610.20	0.629E-02	0.572E-02	0.108E-02	2.41	34.87	48.88
1900.00	5	474.85	0.606E-02	0.539E-02	0.110E-02	2.33	22.73	32.58
1900.00	6	417.75	0.554E-02	0.492E-02	0.111E-02	2.18	18.38	27.20
1900.00	7	365.64	0.503E-02	0.447E-02	0.112E-02	1.97	15.30	21.24
1900.00	8	506.00	0.532E-02	0.475E-02	0.110E-02	2.04	13.12	24.17
1900.00	9	622.30	0.837E-02	0.770E-02	0.107E-02	2.40	65.11	81.43
1900.00	10	653.72	0.854E-02	0.789E-02	0.100E-02	3.41	62.38	82.22
1900.00	11	644.21	0.848E-02	0.787E-02	0.100E-02	3.22	61.07	80.59
1900.00	12	646.10	0.848E-02	0.788E-02	0.100E-02	3.22	61.04	80.63
2000.00	1	926.56	0.714E-02	0.645E-02	0.102E-02	2.57	78.40	111.71
2000.00	2	913.84	0.638E-02	0.575E-02	0.102E-02	2.20	78.18	110.84
2000.00	3	782.00	0.525E-02	0.471E-02	0.105E-02	1.84	93.88	121.02
2000.00	4	655.52	0.525E-02	0.550E-02	0.107E-02	2.34	37.31	53.75
2000.00	5	505.00	0.642E-02	0.573E-02	0.110E-02	2.48	25.18	35.23
2000.00	6	456.16	0.547E-02	0.487E-02	0.111E-02	2.11	21.80	30.88
2000.00	7	395.97	0.474E-02	0.421E-02	0.112E-02	1.85	17.15	24.28
2000.00	8	512.92	0.678E-02	0.605E-02	0.109E-02	2.50	15.72	26.94
2000.00	9	685.54	0.620E-02	0.555E-02	0.107E-02	2.32	71.43	88.34
2000.00	10	601.34	0.918E-02	0.819E-02	0.106E-02	2.47	65.63	87.04
2000.00	11	577.56	0.904E-02	0.806E-02	0.106E-02	3.43	64.50	86.23
2000.00	12	576.70	0.904E-02	0.806E-02	0.106E-02	3.43	64.47	86.23
2100.00	1	982.82	0.849E-02	0.767E-02	0.101E-02	3.03	81.43	118.88
2100.00	2	984.01	0.795E-02	0.717E-02	0.101E-02	2.88	81.01	118.23
2100.00	3	784.28	0.554E-02	0.498E-02	0.104E-02	2.03	95.72	124.22
2100.00	4	718.62	0.593E-02	0.532E-02	0.106E-02	2.20	39.81	56.01
2100.00	5	612.46	0.744E-02	0.662E-02	0.109E-02	2.88	28.93	39.34
2100.00	6	464.85	0.576E-02	0.513E-02	0.110E-02	2.22	22.72	33.94
2100.00	7	435.43	0.458E-02	0.409E-02	0.111E-02	1.76	18.83	27.38
2100.00	8	520.36	0.805E-02	0.723E-02	0.108E-02	3.10	18.61	30.31
2100.00	9	707.57	0.590E-02	0.530E-02	0.106E-02	2.20	73.82	88.01
2100.00	10	626.53	0.885E-02	0.792E-02	0.107E-02	3.33	68.18	91.97
2100.00	11	617.43	0.889E-02	0.795E-02	0.107E-02	3.35	67.85	90.00
2100.00	12	618.61	0.887E-02	0.793E-02	0.107E-02	3.34	67.61	90.00
2200.00	1	1055.25	0.857E-02	0.775E-02	0.993E-03	3.02	84.46	132.31
2200.00	2	1014.52	0.831E-02	0.752E-02	0.100E-02	2.95	82.98	120.36
2200.00	3	836.81	0.556E-02	0.501E-02	0.103E-02	2.03	87.78	127.77
2200.00	4	738.78	0.555E-02	0.499E-02	0.105E-02	2.08	41.57	60.80
2200.00	5	615.65	0.845E-02	0.754E-02	0.109E-02	3.24	31.28	42.50
2200.00	6	505.00	0.612E-02	0.549E-02	0.110E-02	2.35	25.97	37.12
2200.00	10	665.35	0.838E-02	0.751E-02	0.106E-02	3.13	72.28	95.81
2200.00	11	655.28	0.843E-02	0.755E-02	0.107E-02	3.18	71.01	94.81
2200.00	12	656.26	0.841E-02	0.753E-02	0.107E-02	3.15	70.98	94.65
2300.00	1	1117.80	0.760E-02	0.707E-02	0.982E-03	2.73	87.18	127.27
2300.00	2	1068.04	0.760E-02	0.707E-02	0.988E-03	2.74	88.70	135.73
2300.00	3	882.74	0.842E-02	0.486E-02	0.102E-02	1.86	90.72	131.38
2300.00	4	747.40	0.513E-02	0.460E-02	0.105E-02	1.90	42.47	63.10
2300.00	5	622.83	0.911E-02	0.813E-02	0.109E-02	3.48	34.75	46.32
2300.00	6	610.40	0.693E-02	0.618E-02	0.110E-02	2.65	26.72	38.66
2300.00	7	505.00	0.458E-02	0.410E-02	0.110E-02	1.75	22.43	33.48
2300.00	8	580.57	0.323E-02	0.289E-02	0.108E-02	1.23	21.18	34.64
2300.00	9	741.42	0.532E-02	0.478E-02	0.105E-02	1.97	77.86	104.28
2300.00	10	736.80	0.780E-02	0.700E-02	0.105E-02	2.89	75.17	101.80
2300.00	11	718.82	0.787E-02	0.706E-02	0.106E-02	2.92	73.93	98.71
2300.00	12	718.52	0.787E-02	0.706E-02	0.106E-02	2.92	73.86	98.66
2400.00	1	1131.31	0.688E-02	0.626E-02	0.982E-03	2.41	88.88	128.81
2400.00	2	1118.12	0.682E-02	0.626E-02	0.982E-03	2.42	88.12	128.28
2400.00	3	882.35	0.522E-02	0.471E-02	0.102E-02	1.89	101.61	133.02
2400.00	4	779.27	0.350E-02	0.314E-02	0.104E-02	1.30	44.76	66.84
2400.00	5	658.12	0.316E-02	0.284E-02	0.108E-02	1.21	38.88	48.74
2400.00	6	614.85	0.781E-02	0.570E-02	0.108E-02	2.84	31.00	43.99
2400.00	7	511.17	0.525E-02	0.468E-02	0.110E-02	2.01	24.44	35.81
2400.00	8	615.88	0.330E-02	0.296E-02	0.107E-02	1.25	22.43	37.20
2400.00	9	750.59	0.510E-02	0.458E-02	0.105E-02	1.89	78.55	108.48
2400.00	10	740.65	0.722E-02	0.648E-02	0.105E-02	2.67	77.85	104.42
2400.00	11	736.64	0.728E-02	0.654E-02	0.105E-02	2.70	76.83	103.14
2400.00	12	736.64	0.728E-02	0.654E-02	0.105E-02	2.70	76.88	103.08
2500.00	1	1125.43	0.620E-02	0.562E-02	0.981E-03	2.16	91.75	132.12
2500.00	2	1122.31	0.620E-02	0.562E-02	0.982E-03	2.16	91.28	131.84
2500.00	3	900.84	0.501E-02	0.451E-02	0.102E-02	1.81	103.41	135.73
2500.00	4	812.80	0.277E-02	0.229E-02	0.104E-02	1.26	48.13	68.12
2500.00	5	682.61	0.323E-02	0.289E-02	0.106E-02	1.23	37.18	50.62
2500.00	6	520.70	0.787E-02	0.702E-02	0.109E-02	3.01	34.81	46.12
2500.00	7	513.72	0.583E-02	0.520E-02	0.109E-02	2.23	26.86	37.62
2500.00	8	651.80	0.330E-02	0.295E-02	0.107E-02	1.24	23.57	38.58
2500.00	9	787.08	0.347E-02	0.312E-02	0.105E-02	1.26	80.83	108.26
2500.00	10	746.51	0.661E-02	0.593E-02	0.105E-02	2.44	80.29	107.18
2500.00	11	744.22	0.668E-02	0.600E-02	0.105E-02	2.47	79.10	105.80
2500.00	12	744.22	0.668E-02	0.600E-02	0.105E-02	2.47	79.05	105.75
2600.00	1	1160.73	0.642E-02	0.582E-02	0.975E-03	2.23	93.88	135.82
2600.00	2	1128.62	0.565E-02	0.512E-02	0.981E-03	1.97	93.25	132.87
2600.00	3	936.29	0.384E-02	0.345E-02	0.101E-02	1.41	104.83	138.42
2600.00	4	853.14	0.386E-02	0.346E-02	0.103E-02	1.41	47.54	70.87
2600.00	5	613.51	0.321E-02	0.287E-02	0.106E-02	1.21	38.40	52.23
2600.00	6	526.53	0.809E-02	0.722E-02	0.109E-02	3.09	27.70	40.42
2600.00	7	616.76	0.620E-02	0.553E-02	0.109E-02	2.37	28.05	40.48
2600.00	8	688.87	0.316E-02	0.285E-02	0.108E-02	1.19	24.86	42.38
2600.00	9	782.12	0.334E-02	0.304E-02	0.104E-02	1.24	82.07	110.13
2600.00	10	773.28	0.350E-02	0.314E-02	0.104E-02	1.28	81.58	109.32
2600.00	11	765.36	0.323E-02	0.290E-02	0.105E-02	1.19	80.30	107.75
2600.00	12	764.82	0.323E-02	0.290E-02	0.105E-02	1.19	80.26	107.68
2700.00	1	1189.22	0.566E-02	0.506E-02	0.970E-03	2.27	96.24	136.81
2700.00	2	1181.34	0.583E-02	0.528E-02	0.975E-03	2.08	95.31	135.89

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2700.00     3   884.74 0.387E-02 0.359E-02 0.101E-02    1.42  108.28  141.00
2700.00     4   882.00 0.379E-02 0.342E-02 0.102E-02    1.37   48.81   73.83
2700.00     5   850.86 0.313E-02 0.281E-02 0.107E-02    1.18   39.57   55.75
2700.00     6   871.23 0.270E-02 0.241E-02 0.108E-02    1.02   38.73   52.08
2700.00     7   823.59 0.642E-02 0.572E-02 0.109E-02    2.48   31.89   43.11
2700.00    11   788.42 0.350E-02 0.314E-02 0.104E-02    1.29   81.56  108.79
2700.00    12   786.42 0.350E-02 0.314E-02 0.104E-02    1.29   81.53  108.78
2800.00     1  1222.28 0.632E-02 0.574E-02 0.884E-03    2.17   98.42  142.27
2800.00     2  1188.61 0.588E-02 0.534E-02 0.870E-03    2.03   97.34  138.81
2800.00     3  1000.70 0.388E-02 0.349E-02 0.100E-02    1.37  107.62  143.82
2800.00     4   892.88 0.360E-02 0.324E-02 0.102E-02    1.30   50.21   75.09
2800.00     5   881.67 0.309E-02 0.268E-02 0.108E-02    1.11   40.89   56.33
2800.00     6   898.22 0.288E-02 0.237E-02 0.108E-02    1.06   38.73   53.85
2800.00     7   831.13 0.648E-02 0.579E-02 0.109E-02    2.48   33.88   45.89
2800.00     8   739.08 0.279E-02 0.251E-02 0.108E-02    1.03   27.01   48.38
2800.00     9   818.02 0.311E-02 0.280E-02 0.104E-02    1.14   84.40  113.75
2800.00    10   828.24 0.382E-02 0.343E-02 0.103E-02    1.39   84.34  114.09
2800.00    11   812.80 0.365E-02 0.326E-02 0.104E-02    1.33   82.92  112.06
2800.00    12   812.80 0.365E-02 0.326E-02 0.104E-02    1.33   82.87  112.03
2900.00     1  1288.00 0.583E-02 0.531E-02 0.958E-03    1.89  100.41  145.58
2900.00     2  1212.30 0.561E-02 0.510E-02 0.888E-03    1.82   99.26  142.77
2900.00     3  1030.27 0.368E-02 0.333E-02 0.998E-03    1.30  108.83  145.69
2900.00     4   901.18 0.338E-02 0.306E-02 0.102E-02    1.22   51.43   76.59
2900.00     5   731.82 0.277E-02 0.249E-02 0.105E-02    1.03   41.72   60.78
2900.00     6   828.08 0.258E-02 0.226E-02 0.107E-02    0.95   40.89   55.94
2900.00     7   867.67 0.218E-02 0.183E-02 0.108E-02    0.82   34.80   46.00
2900.00     8   748.87 0.258E-02 0.231E-02 0.105E-02    0.85   27.97   47.55
2900.00     9   828.34 0.284E-02 0.265E-02 0.103E-02    1.07   85.46  115.48
2900.00    10   884.82 0.377E-02 0.338E-02 0.103E-02    1.37   85.70  118.72
2900.00    11   847.72 0.367E-02 0.330E-02 0.103E-02    1.34   84.28  114.87
2900.00    12   848.48 0.367E-02 0.330E-02 0.103E-02    1.34   84.21  114.84
3000.00     1  1294.08 0.530E-02 0.483E-02 0.952E-03    1.80  102.22  148.84
3000.00     2  1240.78 0.520E-02 0.473E-02 0.861E-03    1.78  101.08  146.57
3000.00     3  1058.64 0.338E-02 0.307E-02 0.993E-03    1.20  110.12  148.03
3000.00     4   923.24 0.288E-02 0.260E-02 0.102E-02    1.04   52.47   78.77
3000.00     5   741.28 0.255E-02 0.220E-02 0.105E-02    0.94   42.88   62.08
3000.00     6   850.88 0.241E-02 0.216E-02 0.107E-02    0.90   41.60   57.77
3000.00     7   901.63 0.208E-02 0.187E-02 0.108E-02    0.78   35.80   48.85
3000.00     8   784.18 0.223E-02 0.200E-02 0.108E-02    0.88   28.83   48.71
3000.00     9   849.61 0.275E-02 0.247E-02 0.103E-02    1.00   88.46  118.88
3000.00    10   888.00 0.362E-02 0.325E-02 0.102E-02    1.31   87.02  118.91
3000.00    11   882.65 0.360E-02 0.324E-02 0.102E-02    1.30   85.56  117.22
3000.00    12   882.55 0.360E-02 0.324E-02 0.102E-02    1.30   85.51  117.17
3100.00     1  1331.88 0.476E-02 0.434E-02 0.945E-03    1.61  103.83  151.61
3100.00     2  1288.43 0.474E-02 0.431E-02 0.858E-03    1.62  102.88  148.18
3100.00     3  1078.50 0.313E-02 0.284E-02 0.988E-03    1.10  111.23  149.85
3100.00     4   981.39 0.288E-02 0.260E-02 0.101E-02    1.03   53.50   80.81
3100.00     5   748.07 0.231E-02 0.207E-02 0.105E-02    0.85   43.51   63.07
3100.00     6   875.27 0.224E-02 0.200E-02 0.106E-02    0.84   42.43   59.48
3100.00     7   913.50 0.199E-02 0.178E-02 0.108E-02    0.75   36.35   51.18
3100.00     8   776.71 0.184E-02 0.175E-02 0.104E-02    0.72   29.54   50.23
3100.00     9   882.50 0.258E-02 0.232E-02 0.103E-02    0.94   87.41  118.38
3100.00    10   893.92 0.343E-02 0.309E-02 0.102E-02    1.24   88.25  120.32
3100.00    11   881.72 0.343E-02 0.308E-02 0.102E-02    1.24   86.80  118.78
3100.00    12   881.72 0.340E-02 0.307E-02 0.102E-02    1.23   86.74  118.73
3200.00     1  1388.21 0.420E-02 0.384E-02 0.938E-03    1.41  105.24  154.33
3200.00     2  1297.88 0.428E-02 0.390E-02 0.851E-03    1.45  104.13  150.89
3200.00     3  1101.83 0.284E-02 0.256E-02 0.985E-03    1.00  112.22  151.75
3200.00     4   988.74 0.277E-02 0.250E-02 0.101E-02    0.99   54.48   82.82
3200.00     5   757.01 0.207E-02 0.185E-02 0.105E-02    0.78   44.28   64.26
3200.00     6   897.57 0.204E-02 0.183E-02 0.106E-02    0.76   43.18   61.04
3200.00     7   827.78 0.187E-02 0.167E-02 0.107E-02    0.70   37.08   52.76
3200.00     8   795.67 0.184E-02 0.175E-02 0.104E-02    0.71   30.28   51.83
3200.00    12   895.28 0.321E-02 0.288E-02 0.102E-02    1.18   87.90  120.05
3300.00     1  1404.88 0.372E-02 0.340E-02 0.933E-03    1.24  106.46  155.66
3300.00     2  1325.27 0.382E-02 0.348E-02 0.847E-03    1.29  105.43  152.97
3300.00     3  1117.80 0.258E-02 0.235E-02 0.982E-03    0.90  113.13  153.22
3300.00     4  1020.73 0.259E-02 0.234E-02 0.100E-02    0.92   55.40   84.85
3300.00     5   784.18 0.182E-02 0.164E-02 0.105E-02    0.67   44.85   65.10
3300.00     6   725.17 0.182E-02 0.164E-02 0.106E-02    0.66   42.87   62.71
3300.00     7   884.75 0.176E-02 0.157E-02 0.107E-02    0.69   37.71   54.38
3300.00     8   818.23 0.180E-02 0.171E-02 0.104E-02    0.69   30.88   53.17
3300.00     9   888.59 0.219E-02 0.197E-02 0.102E-02    0.79   89.07  120.86
3300.00    10   908.17 0.284E-02 0.265E-02 0.102E-02    1.08   90.47  122.97
3300.00    11   902.45 0.299E-02 0.269E-02 0.102E-02    1.08   89.04  121.42
3300.00    12   902.85 0.301E-02 0.272E-02 0.102E-02    1.08   88.99  121.37
3400.00     1  1422.40 0.328E-02 0.300E-02 0.930E-03    1.08  107.58  156.81
3400.00     2  1353.13 0.340E-02 0.310E-02 0.842E-03    1.15  106.57  155.12
3400.00     3  1120.20 0.223E-02 0.212E-02 0.982E-03    0.82  113.94  154.13
3400.00     4  1041.40 0.241E-02 0.218E-02 0.998E-03    0.86   56.28   86.44
3400.00     5   801.08 0.139E-02 0.125E-02 0.104E-02    0.51   45.48   67.02
3400.00     6   728.90 0.163E-02 0.146E-02 0.105E-02    0.60   44.47   63.72
3400.00     7   881.53 0.158E-02 0.142E-02 0.108E-02    0.58   38.30   55.89
3400.00     8   838.75 0.182E-02 0.164E-02 0.103E-02    0.65   31.62   54.48
3400.00     9   888.00 0.199E-02 0.180E-02 0.102E-02    0.72   88.79  121.88
3400.00    10   933.24 0.262E-02 0.237E-02 0.102E-02    0.94   91.41  124.69
3400.00    11   925.87 0.252E-02 0.227E-02 0.102E-02    0.91   89.95  123.18
3400.00    12   908.59 0.277E-02 0.250E-02 0.102E-02    1.00   89.99  122.86
3500.00     1  1428.84 0.287E-02 0.262E-02 0.930E-03    0.96  108.53  159.88
3500.00     2  1378.85 0.301E-02 0.275E-02 0.838E-03    1.01  107.59  156.98
3500.00     3  1122.80 0.211E-02 0.192E-02 0.982E-03    0.74  114.88  154.88
3500.00     4  1061.39 0.219E-02 0.198E-02 0.982E-03    0.77   57.03   87.93
3500.00     5   821.94 0.130E-02 0.128E-02 0.104E-02    0.51   45.88   68.28
3500.00     6   747.48 0.141E-02 0.127E-02 0.105E-02    0.52   44.88   64.83
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3500.00      7   715.82 0.141E-02 0.128E-02 0.108E-02    0.52    38.82    57.32
3500.00      8   864.17 0.173E-02 0.158E-02 0.103E-02    0.63    33.34    85.71
3500.00      9   881.31 0.180E-02 0.162E-02 0.102E-02    0.65    86.44   132.42
3500.00     10   952.71 0.255E-02 0.230E-02 0.101E-02    0.51    93.33   136.50
3500.00     11   941.47 0.252E-02 0.227E-02 0.101E-02    0.50    90.85   134.83
3500.00     12   941.47 0.252E-02 0.227E-02 0.101E-02    0.50    90.88   134.88
3500.00      1  1428.48 0.253E-02 0.231E-02 0.930E-03    0.64   108.38   180.81
3500.00      2  1400.63 0.270E-02 0.246E-02 0.934E-03    0.50   106.48   168.74
3500.00      3  1128.23 0.193E-02 0.175E-02 0.961E-03    0.67   115.38   155.83
3500.00      4  1060.12 0.187E-02 0.174E-02 0.969E-03    0.55    97.72    69.39
3500.00      5   844.55 0.134E-02 0.120E-02 0.103E-02    0.48    48.48    89.87
3500.00      6   752.19 0.119E-02 0.107E-02 0.105E-02    0.44    48.43    85.24
3500.00      7   738.80 0.124E-02 0.111E-02 0.105E-02    0.48    38.38    56.53
3500.00      8   871.58 0.163E-02 0.147E-02 0.103E-02    0.58    33.83    58.83
3500.00      9   888.14 0.185E-02 0.149E-02 0.102E-02    0.60    81.04   123.18
3500.00     10   958.01 0.244E-02 0.221E-02 0.101E-02    0.87    93.20   127.86
3500.00     11   958.74 0.244E-02 0.224E-02 0.101E-02    0.88    91.74   128.13
3500.00     12   957.58 0.244E-02 0.221E-02 0.101E-02    0.87    91.78   128.12
From file fec18_3,  FI=1000 C days, 1.8 m x 5 cm insulation.

        TOTAL HEAVE


        TIME =       0.0
        SEGREGATIONAL HEAVE
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0


        TIME =     100.00
        SEGREGATIONAL HEAVE
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0

        TOTAL HEAVE
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0


        TIME =     200.00
        SEGREGATIONAL HEAVE
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0

        TOTAL HEAVE
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0


        TIME =     300.00
        SEGREGATIONAL HEAVE
 3.83     3.85     4.00     0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0

        TOTAL HEAVE
 7.41     7.37     7.00     0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0


        TIME =     400.00
        SEGREGATIONAL HEAVE
 8.44     8.48     8.80     0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0

        TOTAL HEAVE
13.83    13.79    12.83     0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0


        TIME =     500.00
        SEGREGATIONAL HEAVE
11.54    11.58    14.04     0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0

        TOTAL HEAVE
18.59    18.47    20.38     0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0


        TIME =     600.00
        SEGREGATIONAL HEAVE
15.81    15.86    20.75     0.0      0.0      0.0      0.0      0.0      0.0      5.85     8.82     8.82

        TOTAL HEAVE
25.84    25.80    28.80     0.87     0.31     0.02     0.0      0.0      0.0      8.78     9.80     9.88


        TIME =     700.00
        TOTAL HEAVE
32.47    32.43    38.48     1.54     0.91     0.59     0.0      0.0     10.61    17.91    18.15    16.18


        TIME =     800.00
        SEGREGATIONAL HEAVE
27.53    27.57    34.05     0.0      0.0      0.0      0.0      0.0     15.87    22.32    22.18    22.18
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          TOTAL HEAVE
  40.84    40.70   45.47     2.04     1.43     1.11     0.88     0.0     19.87    27.17    27.55    27.56


          TIME =      900.00
          SEGREGATIONAL HEAVE
  33.01    33.26   41.47     0.0      0.0      0.0      0.0      0.0     24.47    31.08    30.82    30.80

          TOTAL HEAVE
  50.02    49.72   54.96     2.55     1.89     1.58     1.12     0.27    30.48    37.42    37.34    37.32


          TIME =     1000.00
          SEGREGATIONAL HEAVE
  37.39    37.81   48.06     4.43     0.0      0.0      0.0      0.0     29.01    33.18    32.92    32.91

          TOTAL HEAVE
  55.51    55.51   64.50     7.28     2.32     2.03     1.84     1.26    36.33    40.27    40.53    40.57


          TIME =     1100.00
          SEGREGATIONAL HEAVE
  42.53    42.88   54.08     7.74     0.0      0.0      0.0      0.0     33.83    35.53    35.18    35.17

          TOTAL HEAVE
  61.52    62.06   72.28    11.50     2.87     2.41     2.08     1.96    43.85    44.42    44.74    44.82


          TIME =     1200.00
          SEGREGATIONAL HEAVE
  47.85    48.19   60.34    10.88     3.99     0.0      0.0      0.0     39.90    38.11    37.88    37.88

          TOTAL HEAVE
  68.89    68.73   78.67    15.76     6.88     2.73     2.49     2.47    50.95    48.20    47.84    47.84


          TIME =     1300.00
          SEGREGATIONAL HEAVE
  53.11    53.47   64.90    14.19     7.38     3.79     0.0      0.0     45.89    41.37    40.83    40.88

          TOTAL HEAVE
  75.88    75.89   83.84    22.10    10.35     6.84     2.78     2.83    59.01    52.32    51.92    51.95

  58.21    58.82   69.26    17.75    10.34     8.97     3.30     2.83    51.89    45.28    44.50    44.53

          TOTAL HEAVE
  83.76    83.43   89.26    27.72    14.07     9.85     6.15     5.70    67.24    57.65    57.07    57.15


          TIME =     1500.00
          SEGREGATIONAL HEAVE
  63.10    63.55   73.96    22.17    13.02     9.82     6.22     5.08    56.90    49.13    48.20    48.23

          TOTAL HEAVE
  89.87    90.03   95.08    33.27    17.54    13.58     9.09     8.96    74.84    64.20    62.85    63.03


          TIME =     1600.00
          SEGREGATIONAL HEAVE
  65.38    65.70   78.58    27.03    15.56    12.47     8.82     7.14    62.08    52.57    51.87    51.88

          TOTAL HEAVE
  92.86    92.77  101.11    38.13    21.06    16.92    11.71    12.38    80.48    70.72    69.13    69.25


          TIME =     1700.00
          SEGREGATIONAL HEAVE
  68.53    68.89   83.15    30.18    18.01    14.93    11.18     9.13    64.33    55.92    54.88    54.84

          TOTAL HEAVE
  97.40    98.98  107.31    42.21    24.77    20.26    15.33    16.08    83.78    74.28    73.17    73.15


          TIME =     1800.00
          SEGREGATIONAL HEAVE
  72.23    72.30   87.57    32.85    20.39    17.24    13.33    11.06    66.71    58.95    57.83    57.81

          TOTAL HEAVE
 103.85   102.94  112.98    45.72    26.80    23.72    18.28    20.11    87.41    77.42    76.26    76.24


          TIME =     1900.00
          SEGREGATIONAL HEAVE
  76.83    76.86   91.75    34.97    22.72    19.39    15.30    13.12    68.11    62.38    61.07    61.04

          TOTAL HEAVE
```

```
107.88  107.84  118.31   49.88   32.88   27.20   21.24   24.17   81.43   82.22   80.59   80.53


         TIME =    2000.00
         SEGREGATIONAL HEAVE
 78.60    78.16   93.88   37.21   25.16   21.50   17.15   15.73   71.43   65.63   64.50   64.47

         TOTAL HEAVE
111.71   110.94  121.02   53.78   36.33   30.59   24.29   28.94   85.34   87.04   85.23   85.23
         TIME =    2100.00
         SEGREGATIONAL HEAVE
 81.43    81.01   95.72   39.51   28.03   23.72   18.93   16.81   73.82   68.16   67.85   67.81

         TOTAL HEAVE
118.96   115.23  124.22   58.01   39.24   33.94   27.38   30.31   88.01   91.87   90.00   90.00


         TIME =    2200.00
         SEGREGATIONAL HEAVE
 84.45    83.99   97.75   41.87   31.26   26.07   20.87   18.96   75.89   72.28   71.01   70.98

         TOTAL HEAVE
122.31   120.36  127.77   60.90   42.90   37.12   30.53   32.93  102.12   98.91   94.91   94.88


         TIME =    2300.00
         SEGREGATIONAL HEAVE
 87.18    86.70   99.72   43.47   34.75   28.72   22.43   21.19   77.86   75.17   73.83   73.86

         TOTAL HEAVE
127.27   125.73  131.36   63.10   45.32   39.86   33.48   34.84  104.25  101.50   98.71   98.68


         TIME =    2400.00
         SEGREGATIONAL HEAVE
 89.58    89.12  101.61   44.75   35.96   31.50   24.44   22.43   78.85   77.85   76.63   76.58

         TOTAL HEAVE
129.81   129.26  133.62   65.54   46.74   42.89   35.61   37.39  106.49  104.42  103.14  103.09


         TIME =    2500.00
         SEGREGATIONAL HEAVE
 91.75    91.28  103.41   46.13   37.19   34.81   26.88   23.67   80.83   80.29   79.10   79.05

         TOTAL HEAVE
132.12   131.54  135.73   68.12   50.92   46.12   37.93   39.86  108.35  107.18  105.80  105.75


         TIME =    2600.00
         SEGREGATIONAL HEAVE
 93.98    93.25  104.83   47.54   38.40   37.70   29.05   24.86   82.07   81.86   80.30   80.25

         TOTAL HEAVE
135.92   133.57  138.42   70.97   53.23   48.42   40.48   42.39  110.13  109.32  107.75  107.59


         TIME =    2700.00
         SEGREGATIONAL HEAVE
 96.24    95.31  106.28   48.91   39.57   38.73   31.50   25.98   83.27   82.94   81.56   81.52


         TIME =    2800.00
         SEGREGATIONAL HEAVE
 98.42    97.34  107.82   50.21   40.89   39.73   33.96   27.01   84.40   84.34   82.92   82.87

         TOTAL HEAVE
142.27   139.91  143.52   75.09   58.33   53.95   45.86   46.38  113.75  114.08  112.08  112.03


         TIME =    2900.00
         SEGREGATIONAL HEAVE
100.41    99.28  108.83   51.43   41.72   40.89   34.80   27.57   85.48   85.70   84.25   84.21

         TOTAL HEAVE
145.56   142.77  145.89   76.59   60.76   55.84   48.00   47.95  115.45  115.72  114.87  114.84


         TIME =    3000.00
         SEGREGATIONAL HEAVE
102.22   101.08  110.12   52.47   42.66   41.80   35.80   28.83   86.46   87.03   85.56   85.51

         TOTAL HEAVE
148.64   145.57  148.02   78.77   63.06   57.77   49.85   48.71  116.99  116.91  117.22  117.17
```

```
         TIME =    3100.00
         SEGREGATIONAL HEAVE
103.83   102.88  111.23   53.50   43.51   42.43   36.35   29.54   87.41   88.28   86.80   86.74

         TOTAL HEAVE
151.81   149.16  149.85   80.81   82.07   80.46   51.16   50.23  118.36  120.32  118.78  118.73


         TIME =    3200.00
         SEGREGATIONAL HEAVE
105.24   104.13  112.22   54.49   44.28   43.19   37.05   30.28   88.28   89.40   87.88   87.80

         TOTAL HEAVE
154.32   150.89  151.75   82.82   84.26   81.04   52.78   51.82  119.88  121.70  120.12  120.05


         TIME =    3300.00
         SEGREGATIONAL HEAVE
106.46   105.42  113.13   55.40   44.95   43.87   37.71   30.95   89.07   90.47   89.04   88.89

         TOTAL HEAVE
155.88   152.87  153.22   84.85   85.19   82.71   54.38   53.17  120.88  122.87  121.42  121.37


         TIME =    3400.00
         SEGREGATIONAL HEAVE
158.81   155.12  154.13   86.44   87.02   83.72   55.86   54.46  121.88  124.88  123.16  122.58


         TIME =    3500.00
         SEGREGATIONAL HEAVE
108.53   107.59  114.88   57.03   45.98   44.89   38.82   32.24   90.44   92.32   90.85   90.89

         TOTAL HEAVE
159.96   156.86  154.88   87.83   88.28   84.83   57.32   55.71  122.42  126.50  124.83  124.86


         TIME =    3600.00
         SEGREGATIONAL HEAVE
109.38   108.49  115.35   57.72   46.45   45.43   39.28   32.88   91.04   93.20   91.74   91.78

         TOTAL HEAVE
160.51   158.74  155.83   89.29   89.57   85.24   58.53   56.93  123.18  127.98  126.13  126.12
```

APPENDIX D.

Example problem.

General Site Location and Conditions:

Location - Lacombe, Alberta
Building Type - Steel frame - span length = 4m, gravel pad
Soil Conditions - 10% clay, 10% silt, 80% sand
Liquid limit of the fine fraction of the soil - LLff = 132
Ground Water - Water table 125cm from the surface
Estimate the segregation potential of the soil

Since the soil is a sandy soil the segregation potential is estimated using an Rf factor (Rieke et al, 1983)

[% fines] = [% clay] + [% silt] = 10+10= 20%.
[% clay sizes in fine fraction] = [% clay]/[% fines]
[% clay sizes in fine fraction] = (10/20) 100%= 50%.

Determine R_f from Equation 3.1

$$R_f = \frac{(\%\ \text{fines})\ (\%\ \text{clay sizes in fine fraction})}{(\text{liquid limit of fines fraction})}$$

$$R_f = \frac{20 \times 50}{132}$$

$$R_f = 7.6$$

Determine SP_0 from Figure 3.3

$$SP_0 = 160$$

Estimate the temperature condition at the site.

Mean air freezing index can be determined for this location from Boyd (1973).

MFI = 1389°C days

Design air freezing Index

$$\begin{aligned} DFI &= 100 + 1.29\ (MFI) \\ &= 1892^\circ C \text{ days} \end{aligned}$$

Assume the ground surface is covered with snow over the freezing season, therefore n = 1.

Ground freezing index = n (Air freezing index)
1892°C days

Estimate the possible magnitude of frost heave

The total magnitude of heave is determined from figure 4.20

Total heaveΔh_t = 180 mm

Estimate the allowable heave for the structure

The Canadian Foundation Engineering Manual (1978) recommends a maximum deflection between supports for a frame with metal cladding to be

Δ_{max} = L/240

where L equals the span length
In this case L = 4m

Δ_{max} = (4000/240) = 17mm

The Canadian Foundation Engineering Manual (1978) also recommends limits on total deformation of:

For structures on clay Δ_{max} = 80 mm

For structures on sand Δ_{max} = 40 mm
Total frost heave exceeds criteria for total deformation, therefore some foundation improvement is required.

Design foundation to resist frost heave through use of insulation.

If an insulation layer 1.8m wide and 10 cm thick is used the total heave can be determined by interpolating between Figures 5.11 and 5.12

Δh_t = 30 mm

This meets the requirements for total deflection for the structure.